Application of Systems Thinking in Innovative Teaching Pattern—Chemistry Teaching in High Schools

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Abstracts

In chemistry teaching as part of school education, we should endeavor to link classroom knowledge with scientific practice, to initiate the creativeness and the attitude of observation, imagination, excitation and suspension in their scientific activities. Systems thinking, as a new pattern of thinking and a new method to foster innovation ability, has already accumulated extensive sucessful experience in application in many fields.

In the teaching practice of chemistry teaching in high school, we have used the application software reflecting systems thinking (STELLA) to make a series of teaching programs for experiment. Through a creative teaching process consisting of various levels, we use the modeling method to let students perform simulation experiments on some complicated chemical systems on the operation platform provided by STELLA software, so that processes of scientific research with condition control and factor analysis can be reproduced, and the ability of students in imagination, verification, analysis and evaluation can be developed during their independent study.

Key words: system theory systems thinking scientific method chemistry teaching

I. Introspection of teaching process

We can get a fairly clear knowledge on the formation and development of education transformation after an introspection of the process of education from a system point of view. We may find that the traditional education concept and teaching method is a relatively enclosed and independent system.

In this education system, teachers and students are linked by teaching materials, which remain unchanged over a relatively long period of time, therefore the content of teaching would to a large extent be separated from social demand and development, and the process of teaching for both teachers and students is independent of social activities. Tracing back to the experience of study by teachers, we can say that the study activities of students is a replica of the school life of their teachers in early years. If this cycle goes on for long time, undoubtedly, the ability of students would gradually deteriorate, and our society will be lacking in vigor because there may be only few people growing up with good sense of innovation.

Also, with this education pattern, students as learners are only taught with knowledge by teachers in a passive manner, so their ability may be poor to process information and to think over and solve problems. In addition, the quantity of knowledge will reduce as learners would forget something they have kearned and some of the knowledge will become out of date. In this circumstances, the possibility will be even less that learners will become people really capable of independent thinking, to make analysis of the situation using information in various forms and to conclude their own views. So this type of education will also have adverse effect on perfection of personality of learners.

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As education workers engaged in teaching in high schools, we keep on thinking such questions when facing this continually changing society, rapid developing science and technology and students showing strong desire for knowledge and with distictive characteristics of personality under the propagation condition of multi-element information and knowledge. How should we select the content of teaching and organize the process of teaching?

It may be our initial envisage that the content of teaching should follow the pace of scientific progress and social development, so that students can understand changes of the society we live in at the recognition level they have, and get prepared to better adapt themselves to the society and serve the society. However, the fact is, people produced 10 million new compounds from 1828 when German chemist Friedrich W?hler made the first organic compound to 1991, and produced another 10 million new compounds during the decade from 1991 to 2001. This is just an example reflecting that the quantity of knowledge is in exponential growth in the world today.

We will further retrospect that, an important reason to urge people to continuously study is that the knowledge they accepted during their school education as students will gradually become out of date with the progress of society. This also indicates that schools are quite limited in function in their mission to spread knowledge. So we have such questions: in the course of school education, on which aspects should students be given basic knowledge on the nature and society? What general concepts have indicated the basic laws of development and change of the material world? What kind of fostering in ability will help students in their long-term development behind the knowledge carrier?

In this way, the function of education will shift from simply giving knowledge to students to fostering their ability. Students will get knowledge more through exploration and experiment, instead of simple listening to lectures and reading, so that they feel the thinking activities demonstrated by people in the course that such knowledge became acquired by people. A knowledge system built with such organization will benefit to students in their solving unknown questions in the future. Students receive education for the purpose of harmonic development of society and full display of their individual ability, instead of just making a living.

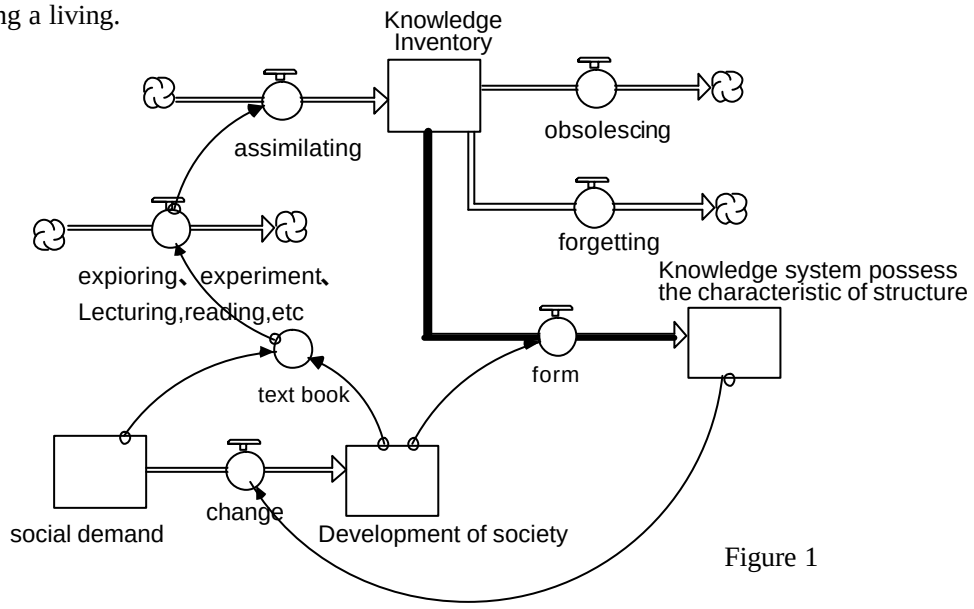


Figure 1

Now it can be understood that, when we shift our goal of education to focusing on mutual adaptation and coordinated development of students with society, the course of education becomes a developing dynamic system with factors of adjustment and control.

II. Birth of "STELLA" application software

In high school chemistry teaching activities, various experiments are windows for students to observe and understand the wonderful world, and the application of systems methods links the mutually independent chemical events or behavior, as important means for students to feel the simplicity of the material world.

It can be said that such changes in teaching concept have been produced along with progress in science and technology. While we feel and enjoy the major changes brought to the course of teaching by computer and multi-media technology and network resources, to our great joy, the application software "STELLA", which can fully embody the characteristics of systems thinking, has provide us at a proper time with an effective tool to realize refreshing in education concept and transition in teaching method in the course of teaching.

First of all, students should be made clear that the so-called "knowledge" is obtained by people through cognition and summing up step by step in their long-term life and practice through observation and purposed experiments, and is not endowed by nature. Briefly, people underwent the following phases in their thinking and analysis to explore the unknown world:

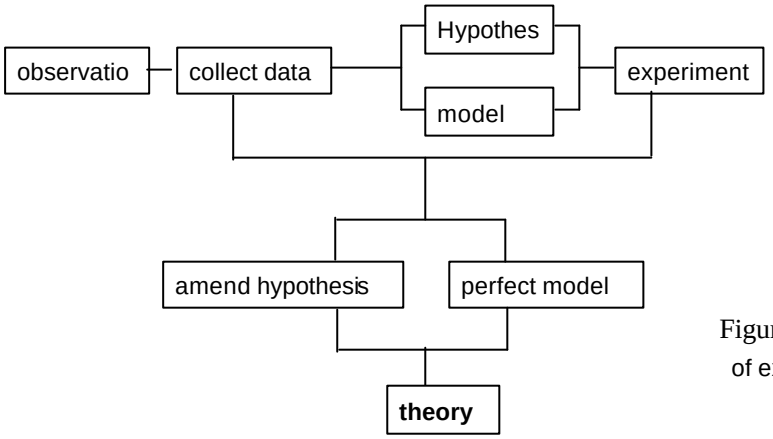


Figure 2 people's cognition of exploring nature

The use of "STELLA" has established an operation platform for assumption, simulation and verification for students in their exploration for relevant knowledge.

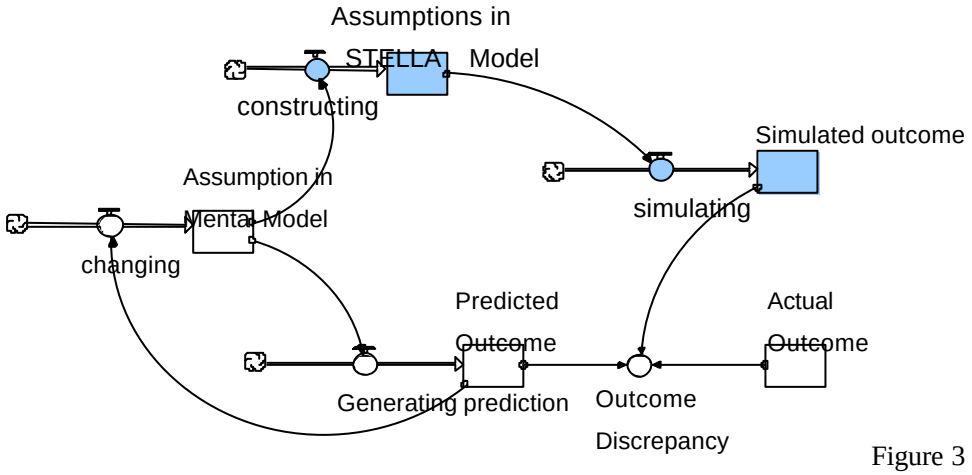


Figure 3

In the teaching practice, students will have the opportunity to feel in person the creativeness, direct view, imagination and excitation in the scientific activities, and to make prediction and decision on possible

results, so as to shape their scientific methods and attitude. This is beyond imagination with traditional teaching.

III. Example of application in chemistry teaching

We performed integration of chemical knowledge using the viewpoint of system theory in conjunction with teaching in chemistry, made verification and simulation test on predictions and assumptions using the "STELLA" software, and achieved good effect in practical teaching activities.

(I) Multi-factor analysis of chemical reaction processes with the powerful numerical modelling function of stella software

It has unique features in analyzing the mutual influence of a number of factors for a matter. To have students learn how to solve problems in the way of systems thinking, they should first be taught to get familiar with and understand the basic structure language and functions of the software. In conjunction with study of relevant sections about chemical reaction rate and chemical equilibrium, we can let students know the functions of basic language units of the "stella" software while they learn the law of variation of chemical reaction rate. In the meantime, the quantitating means of "stella" can effectively deepen students' understanding of the law of variation in chemical reaction rate.

Knowledge on chemical reaction rate and chemical equilibrium is among the important theoretical contents in learning chemistry. The formation and application of the theory are both closely linked with social production and daily life, and also constitute an important area of development in contemporary chemical science. After students know the basic structure language of "stella" software for describing system structure and behavior, we intentionally use this software to help students to better accept and understand the concept about chemical reaction rate.

To start the understanding of chemical reaction rate, students often simply think that chemical reaction rate is the reduction of reacting substances and increase of generated products in a unit time, and such change in quantity is a fixed value, therefore they believe that the concentration variation of reacting substances and generated products will be shown as a first-order linear function graph. The following graph can be obtained by establishing the model using "STELLA" :

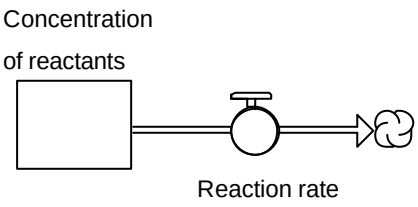


Figure 4

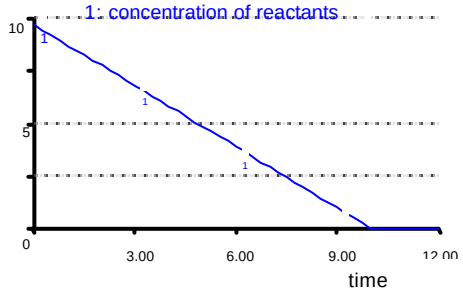


Figure 5

After learning the theory of effective collision related to chemical reaction rate, students can understand that the reaction rate is also related to the concentration of reacting substances, therefore both reacted substance concentration and reaction rate variation become non-linear graphs after relevant link between reacting rate and concentration of reacted products has appeared in the system. This gives a key prompt to the students for them to further try to establish the functional relationship describing the law of reaction rate variation.

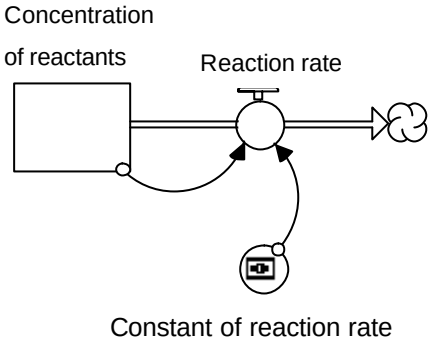


Figure 6

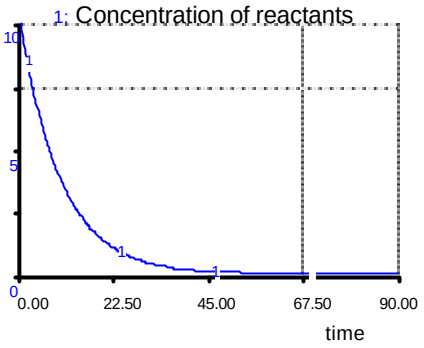


Figure 7

If we further study the reaction characteristics of reversible reactions on the above basis, the structure diagram of the corresponding systems will be converted into the following form:

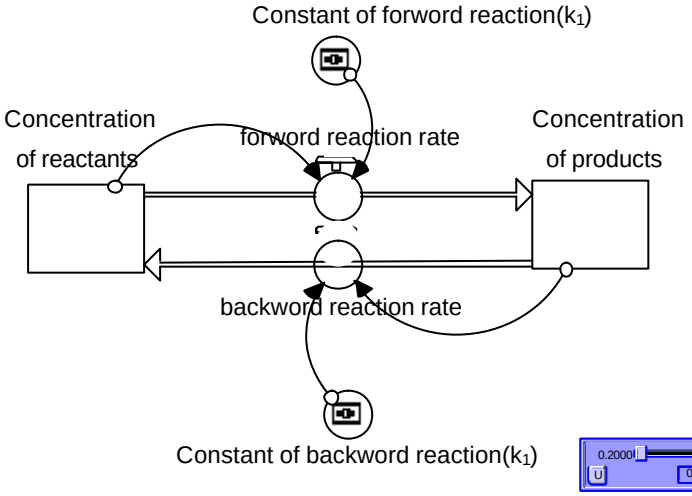


Figure 8

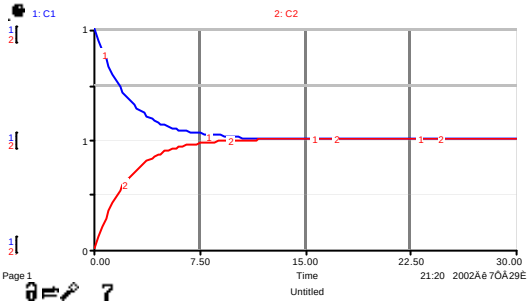


Figure 9

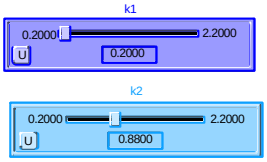


Figure 10

By means of the sliding rod simulator, students can adjust the rate of both normal and reversible reactions on the “STELLA” operation platform, to observe the variation of concentration of reacting substances and generated products in establishing the equilibrium. During the experiment, students would gradually come to some envisages, that the concentration of reacting substances and generated products at equilibrium is correlated with the normal and reversible reaction rate constants, and can be expressed eventually by the ratio of k_1 to k_2. This is how the concept of equilibrium constant was produced. Here, students can further prove it by establishing the functional relations of a new connector.

For complicated systems encountered in study, such as selecting the optimum reacting conditions in the synthesized ammonia reaction system, students can still make the experiment on a relevant “STELLA” platform. First, the following structure model is established according to theories associated with reaction rate (both normal and reversible reactions have the same reaction temperature, and the activating energy of both normal and reversible reactions is mutually linked via reaction heat.):

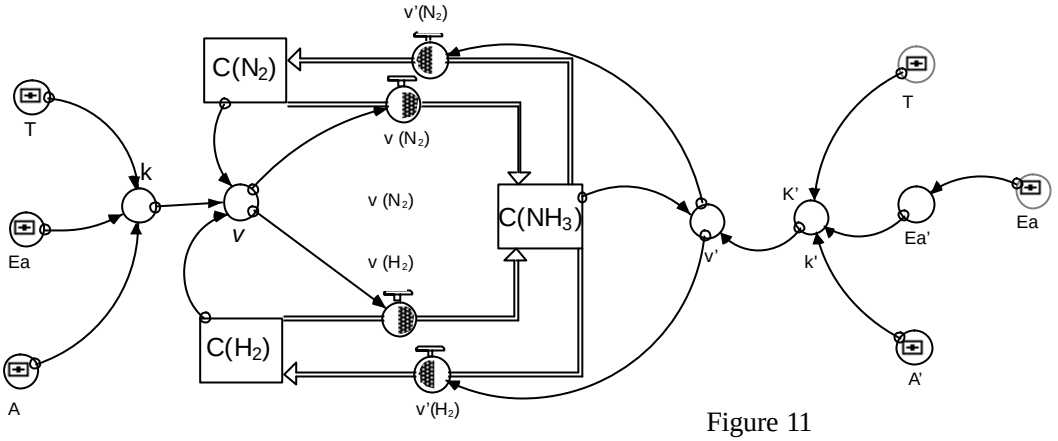


Figure 11

In chemistry teaching of high school, students have acquired initial knowledge to judge the movement of a chemical equilibrium system under the action of external conditions through observation and analysis of visual phenomenon in chemical experiments. In the above structure model, students can perform simulation tests on the chemical equilibrium status under controlled conditions, and one set of data among them is as follows:

(1) Effect of pressure on equilibrium

No.	Pressure (relative)	Temperature (K)	Activating energy ($kJ \cdot mol^{-1}$)	Concentration of each component at equilibrium ($mol \cdot L^{-1}$)			Time for equilibrium establishment
				N_2	H_2	NH_3	
1	1	673	50	0.23	0.71	1.53	168.5
2	5	673	50	0.54	1.63	8.91	92.15
3	10	673	50	0.91	2.73	18.18	26.15

(2) Effect of temperature on equilibrium

No.	Pressure (relative)	Temperature (K)	Activating energy ($kJ \cdot mol^{-1}$)	Concentration of each component at equilibrium ($mol \cdot L^{-1}$)			Time for equilibrium establishment
				N_2	H_2	NH_3	
1	10	473	50	0.64	1.93	18.71	284.30
2	10	573	50	0.79	2.38	18.41	62.03
3	10	673	50	0.91	2.73	18.18	26.15

(3) Effect of activating energy on equilibrium

No.	Pressure (relative)	Temperature (K)	Activating energy ($kJ \cdot mol^{-1}$)	Concentration of each component at equilibrium ($mol \cdot L^{-1}$)			Time for equilibrium establishment
				N_2	H_2	NH_3	
1	10	673	50	0.91	2.73	18.18	26.15
2	10	673	40	0.91	2.73	18.18	12.024
3	10	673	30	0.91	2.73	18.18	5.524

The results of the above simulation tests using "STELLA" have shown that, with the increase of pressure in the reaction system, the reaction rate is increasing (with increased converting rate in reaction and shortened time for equilibrium establishment), and the equilibrium shifts in the direction favoring the

generation of ammonia; when the temperature increases, the reaction rate is increasing, but the equilibrium result does not favor the generation of ammonia. The direct outcome of applying catalyst can lower the activating energy in the reaction, and lowered activating energy can only increase the reaction rate, with no effect on the equilibrium.

Such experiment processes can produce effects on students on at least three levels: firstly, the relevant data obtained in the experiment on the "STELLA" operation platform agree with the trend of variation in experimental data observed for the equilibrium system, indicating the above structure model has been correctly established; secondly, the operations performed on this structure model and the obtained relevant results can deepen the students' understanding on chemical equilibrium system and the associated concepts, they can make repeated experiments and exploration on questions they are interested in or difficult to them, and in the course of establishing model with computer, they will build up their knowledge system with certain organization structure in an active and independent manner; thirdly, during the experiments, students can learn the basic method to perform single-factor analysis under controlled conditions with a subtle influence. Selection of reaction conditions should be the summary and optimization of the results of all the above parts. Such process of cognition of scientific methods should be advocated with great efforts in education.

In industrial production, the synthesizing reaction of ammonia is a continuous production process, during which ammonia is being removed and nitrogen and hydrogen made up in a continuous manner. In the above "STELLA" structure model that has been proved reasonable and able to express the reaction changing characteristics in the course of synthesizing reaction of ammonia, addition of ammonia removal and raw materials make-up will result in a new experimental environment that can be used to simulate and analyze the law of variation of various substances during ammonia synthesizing reaction. The corresponding structure model will then be converted as follows:

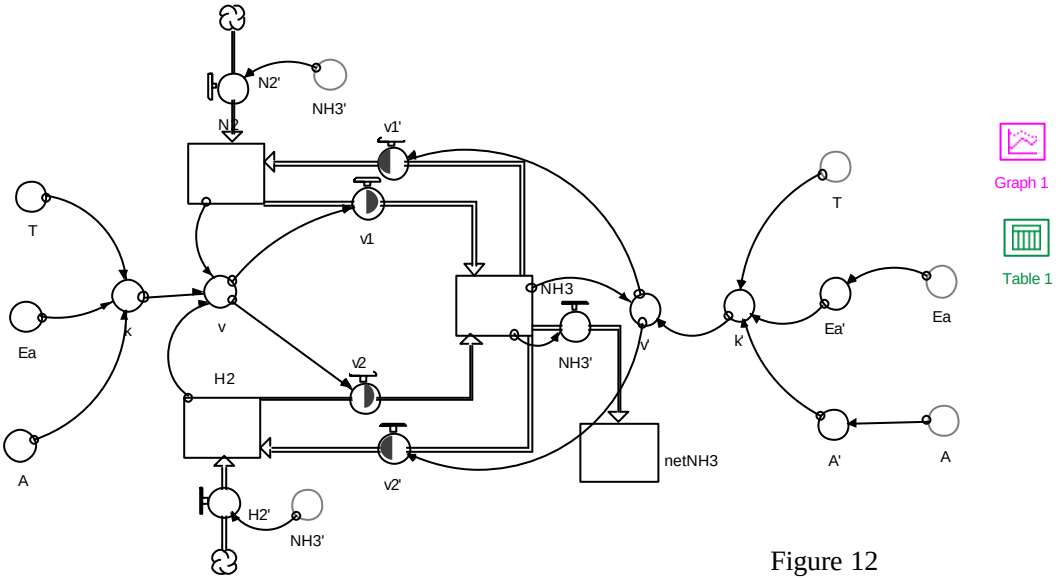


Figure 12

In industrial production, the emphasis of concern would be on the material quantity of ammonia obtained in a unit time, therefore in the simulation process, it is only necessary to insert the analysis of total ammonia, and the corresponding conclusion can be obtained through comparison of data.

The figure to the right shows the variation of concentration or quantity of various substances at 673K, E_a=50kJ·mol^{-1} and a relative pressure of 10.

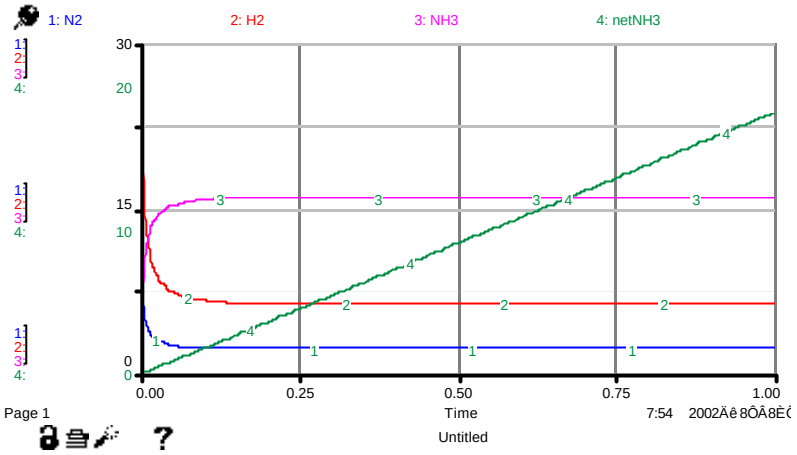


Figure 13

The data in the graph show that once the ammonia synthesizing reaction has been initialized, after a short period of time for adjustment, the reaction will soon come to a dynamic stable status (we can refer it to as **stable status**) under the condition that no equilibrium is established in the course of continuous production. On this operation platform, we can make simulation tests with further changes in conditions, and the results are as listed in the table below:

No.	Pressure (relative)	Temperature (K)	Activating energy (kJ · mol^{-1})	Concentration of each component at equilibrium (mol·L^{-1})			Total NH_3 in unit time
				N_2	H_2	NH_3	
1	10	473	50	4.70	14.11	10.59	62.49
2	10	573	50	3.84	11.52	12.32	73.19
3	10	673	50	3.31	9.94	13.38	79.76
4	5	673	50	2.57	7.71	4.80	28.68
5	1	673	50	0.95	2.86	0.09	5.46
6	10	673	50	3.31	9.94	13.38	79.76
7	10	673	40	2.78	8.35	14.43	86.37
8	10	673	30	2.33	7.00	15.33	92.59

This set of data is so marvellous!

When the above results are compared with experimental data from corresponding equilibrium systems, students will be surprised to find that, the principle of chemical equilibrium movement applicable to an equilibrium system is not completely applicable in a stabilized production process. Relevant data show that the reaction rate is a key factor determining the materials flow rate in a reaction system, and is directly associated with the concentration of various substances in stable status and the total amount of NH_3 obtained in unit time, therefore temperature will produce an effect on the change of concentration of various substances in stable status in a way just opposite to that in the equilibrium status. This agrees with the result that use of catalyst will act upon the variation of concentration of substances in an reaction.

At this point, students have, in the course of modelling in cooperation with computer, consciously formed basic knowledge about the characteristics of stable status that is different from the equilibrium

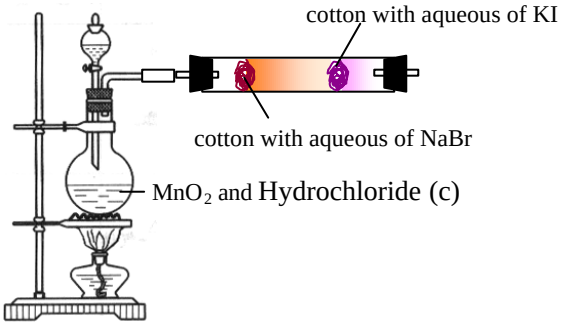
status and can be seen in continuous production process, thus, it promotes the shifting of learners from static and local thinking to dymanic and overall thinking in the understanding of things and their law of variations.

The powerful numerical modelling function of "STELLA" application software has completely changed the previous teaching mode of imbuing. Students can gradually improve their understanding of the development and changes of things in the continuous trials and analyses, feel the joy from initial modelling by tests, through modifying the model with reference to practical experiment data and to the success of experiment, and the surprise in unexpected discovery, so they can deepen their understanding of the knowledge learned in conscious summary. They can learn in the course of cognition the basic process of people to explore the laws of change in the material world, and this is one of the major transforms brought to the teaching mode by the "STELLA" application software.

(II) **Introspection and integration of chemical reaction with systematic views**

In the chemistry course in secondary schools, large number of mutual reactions among substances are involved, and they are classified into two major categories of oxidation-reduction reaction and non-oxidation-reduction reaction according to whether there is transfer of electrons in the reaction. The many and diverse chemical reactions are integrated using the systematic viewpoint, so that students can understand the mutual connections between substances from an overall point of view, and get prepared in both necessary knowledge and ability to further handle complicated issues.

In the following, the oxidation-reduction reaction system is taken as an example to show the changes that have taken place when trivial knowledge has been organized into a system. The actual experiment process is as shown below:



即： $MnO_2 \xrightarrow{\text{Hydrochloride}} Cl_2$

$Cl_2 \xrightarrow{NaBr} Br_2$

$Br_2 \xrightarrow{KI} I_2$

Figure 14

The experiment involves the preparation of Cl_2 and the substitution reaction between Cl_2 and halogen elements of Br_2 and I_2. It can be expressed in a directly perceivable manner with the conception system of redox reaction:

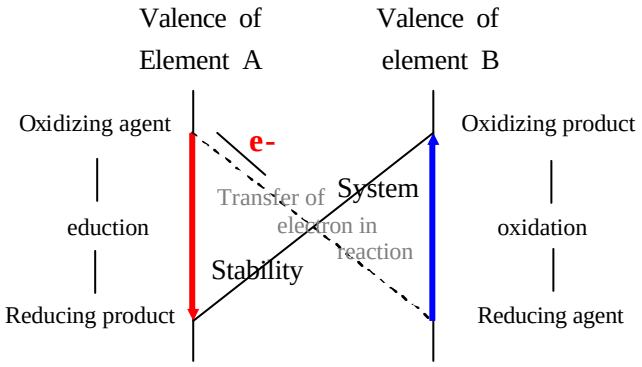
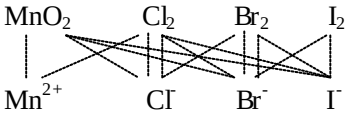


Figure 15 Conception system of redox reaction

By arranging the oxidant, reductant, oxidation product and reduction product in the above reaction according to the relative locations shown in the conceptual diagram and in conjunction with the nature of ion reaction, the local reaction series under acid condition can be obtained as follows:



When the substances are arranged in the order of power in oxidation-reduction property, the resulted reaction system can naturally expand from the above three independent reactions to six types of reactions under strong acid condition that manganese dioxidize can oxidize Cl^-, Br^- and I^-; Cl_2 can oxidize Br^- and I^-; and Br_2 can oxidize I^-, etc. (taking into account the types of ion reaction) In the course of solving the question in the viewpoint of order and connections, the amount of knowledge would increase, and this is the basic viewpoint of the theory of systems, i.e., the entirety is greater than the sum of all localities. The links formed in the system in the meantime are the associated information.

On the basis of the oxidation and reduction reaction system as shown above, other oxidants and their associated reduced products (or reductants and their associated oxidized products) are introduced in the order of relative strength of oxidation and reduction. In this way, the essential link between the simple and orderly property in the law of mutual reaction of substances and the complexity in expression forms has been fully demonstrated on one aspect.

After establishing the viewpoint of systems, the semi-reaction in the oxidation-reduction reaction can be made into a corresponding module using the "STELLA". In the simulation test, students can group the two groups of semi-reactions in a given reaction direction, and after inserting a proper program language, the feasibility of the reaction can be judged on the computer.

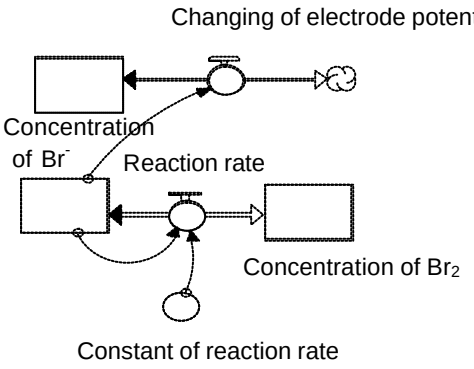


Figure 16 half-reaction module which isn't influenced by pH

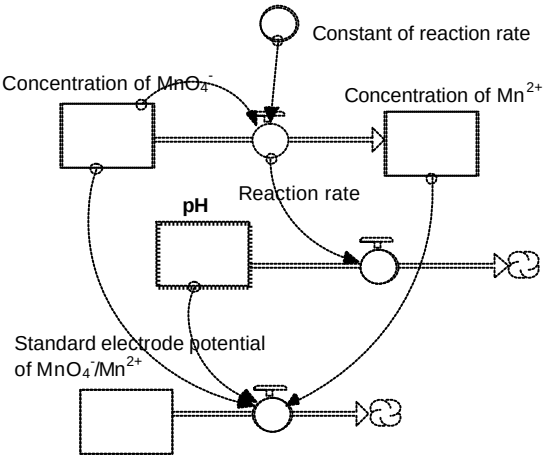


Figure 17 half-reaction module which is influenced by pH

During these combined simulation tests, teachers can further direct students to ponder on the complicated nature of the question: what will be the reaction process when one oxidant meets two reducing substances existing in the reaction system? i.e., if Cl_2 is admitted into the mixed solution containing Br^- and I^-, will Cl_2 oxidize Br^- and I^- at the same time, or difference in the reaction of Cl_2 and that with Br^- and I^- will be shown (i.e., Cl_2 will first oxidize Br^- and then I^-)?

In conjunction with the electrochemical principle, it can be assumed that Cl_2 will first oxidize the reductant in the electron pair with lower electrode potential. To make judgment according to the changing characteristics of electrode potential in the course of reaction and perform simulation on the above

assumption by applying the "STELLA" operation platform, we can obtain the graphs of Br^- and I^- concentration change during the reaction, i.e., the I^- concentration decreases first, and the Br^- concentration decreases afterwards at a certain stage of the reaction. This agrees with the predicted conclusion.

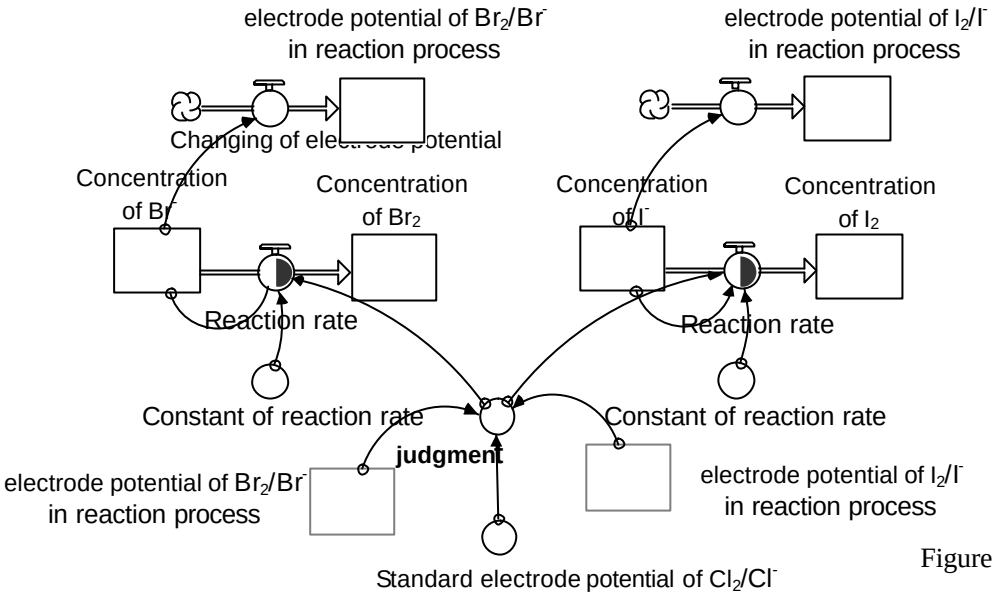


Figure 18

In the meantime, we can make further observations with other tests . First chlorine is admitted into a mixed solution containing NaBr and KI, and CCl_4 is used to extract the halogen element during the reaction. It can be observed that the CCl_4 layer first turns purple red and then orange red. The surprising phenomenon in the test is that, before Br_2 is substituted by Cl_2, the I_2 having been substituted out gradually fades, then the color of Br_2 is shown, and in actual effect, the interference of the color of I_2 on that of Br_2 is avoided, but this phenomenon has not been predicted in advance. This urges students to further ponder on the cause leading to such a phenomenon. This example has well realized the role conversion of students from passive knowledge receiver to knowledge discoverer.

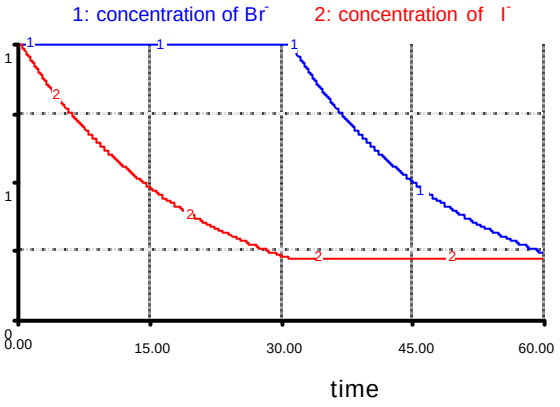


Figure 19

The system thinking on oxidation-reduction reaction system has provided a basis for knowledge transfer in the course of learning for students on their recognition of the non-oxidation-reduction reaction system, which in essence shows the improved ability to learn. Also in the course of learning, students have a direct and real feeling of the coordinated unification of sequence and complexity between matters in nature.

IV. Postscript

When we are pleasantly surprised at the changes in teaching concept and mode brought to us by systems thinking, and when we rethink the structure system of education process, we cannot refuse to cast our attention on one of the important roles in this education system ---- the factor of teachers. The key factors in the process of education to realize the initiative of students in the course of study and to lay a

sound foundation for their long-term development would depends on the transformation of education concepts of teachers and the improvement of their quality.

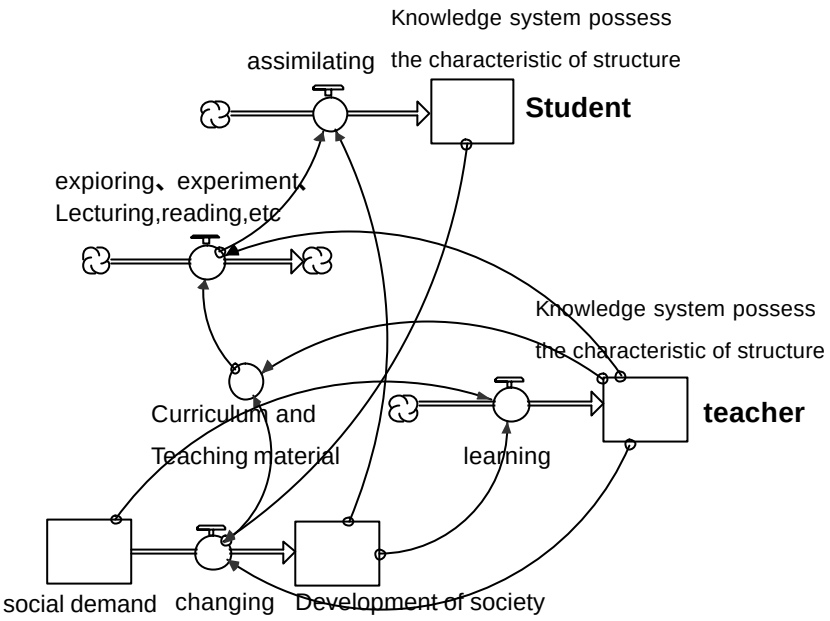


Figure 20

In this sense, it is required that, teachers should, along with the advance of society and growth of students, explore and think the laws in education and teaching process from a broader angle of view, and make systematic processing of the teaching and course of fundamental scientific knowledge and course (the bilateral activities of teachers and students) as mutually relying upon education and learning system, so that the process of learning really embodies its nature of being full of novelty, rich in delight and wit, and worth thinking and exploring. This will also urge teachers to constantly pursue for higher realm of teaching. In this circumstance, there will inevitably be a promotion to the social environment for “a nation with all people learning”.

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