Pleasantly Surprise in Applying System Thinking To Teaching High School Students

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In high school chemistry teaching in China, the calculation of the chemical equation contains some basic types: the direct calculation, the excessive calculation and the dispersion calculation according to of the single equation, the non-associate and associate calculation according to the multi-equations and so on. Their corresponding methods respectively are the direct method, the excessive judgment method, the dispersion method, the establishing the unknown method and dividing to steps method and otherwise. In traditional teaching process, students only accept them passively because it's difficult for them to comprehend the essence of chemical reaction regulation and the chemical reaction processes, then they do a great deal of exercises to strengthen the memory. Therefore, this swallowing method brings on the poor efficiency of study and agility of knowledge control.

This dissertation selects the mix of nitrogen oxygen compound and oxygen dissolving to water calculation as research object. According to the system thinking method, the teacher sets up a series of teaching process from high structure diagram, creating model, imitating the movement to the verification assumption. Teachers and students can observe the variety on the quantity of the chemical reaction more vividly. It brings new understanding through the reflection in process, which promotes the ability of teaching and studying.

* This job has been accomplished with the direct guidance by Professor Wu Xijun (teacher for doctorate students)

The difference between these two kinds of teaching and study patterns is showed as Fig. 1(a), (b).

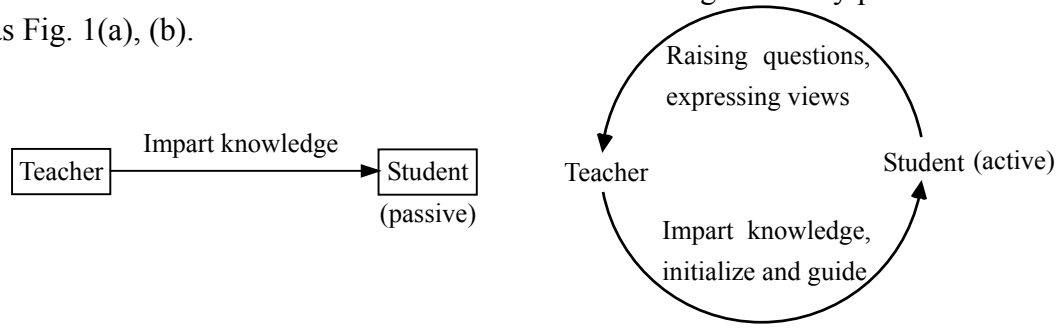

Figure 1(a) comparing of two teaching patterns [3]

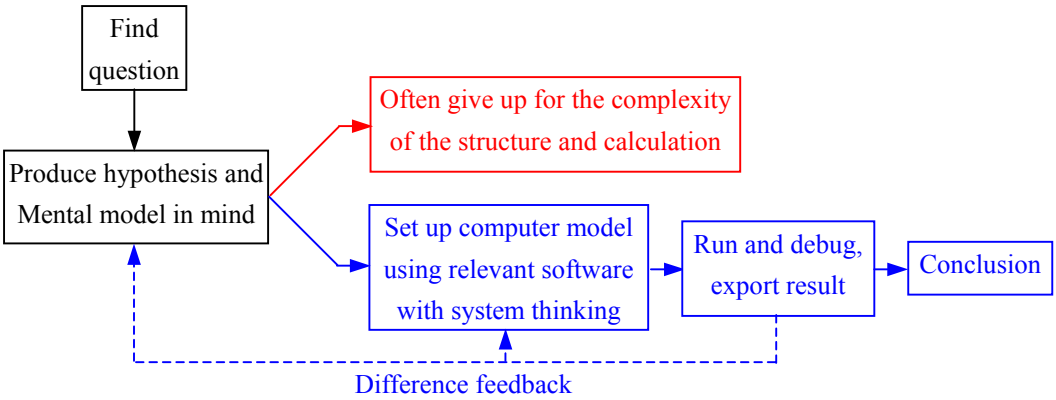

Figure 1(b) comparing of two study thinking patterns

1 The design of chemical equation calculation according to the traditional teaching pattern

Students always encounter similar questions as example 1 and example 2 during the learning process and teachers give some normal ways to solve them.

[E.g. 1] Put the test tube (100mL) of the mixture gas of the 100mL NO_2, O_2 inverted into the sink, the remnant gas volume is 10mL after sufficient reaction. Work out the originally volume makeup of the mixture gas. (Ignore the dissolution of NO, O_2 in the water)

Analysis: (1) The remnant gas is O_2.

$4NO_2 + O_2 + 2H_2O = 4HNO_3$ $\quad \Delta V$

4 1 5

=>72mL =>18mL (100-10)mL

$V(NO_2)$ =72mL, $V(O_2)$ =18 +10 = 28mL

(2) The remnant gas is NO.

$3NO_2 + H_2O = 2HNO_3 + NO$

3 1

=>30mL 10mL

$4NO_2 + O_2 + 2H_2O = 4HNO_3$ $\quad \Delta V$

4 1 5

=>56mL =>14mL (100-30)mL

$V(NO_2)$=56+30 =86mL, $V(O_2)$ =14mL

[E.g. 2] 1 mol of Na, Mg, Al reaction respectively with 1 L hydrochloric acid solution which contains with x mol HCl. Calculate the range of x when the yield of H_2 is: (1)most by Al, (2)the same by Mg and Al, (3)most by Na.

Analysis: $2Na \sim H_2\uparrow$

2 1

1mol =>0.5mol

$Mg + 2HCl = MgCl_2 + H_2\uparrow$

1 2 1

1mol =>2mol =>1mol

$2Al + 6HCl = 2AlCl_3 + 3H_2\uparrow$

2 6 3

1mol =>3mol =>1.5mol

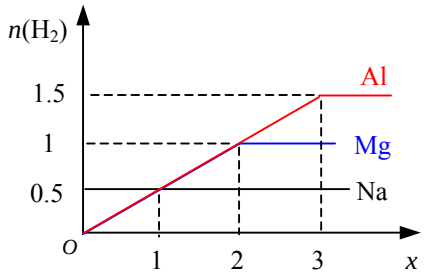

Figure 2 comparing of the yield of H_2 of Na, Mg, Al with the *x* variety

According to Fig. 2, the result is: (1) x > 2; (2) 0<x≤ 2; (3) 0<x<1.

Because these two examples involve complicated thinking progress such as combination, dividing to steps and picture, students face difficulty when study and understand them.

2 The course design of chemical equation calculation based on the system thinking theory

It includes four teaching hours as follows.

2.1 The brief introduction of system thinking software (students' handout, Lesson one)

Here we use "STELLA". Firstly we introduce the essence of system thinking, its difference from the traditional thinking pattern, the significance of learning it, and benefits that students could obtain from it. Then through some examples we explain how to use "STELLA": interface, tools of "STELLA", meaning of icons, and pivotal steps of constructing model.

2.1.1 The brief introduction of the stock and the flow

The value of the stock can get together and be changed by using the flow. And the amount of change of the stock at unit time is equal to the flow. It means such that

$$[\text{Flow}] = \Delta [\text{Stock}] / \Delta t$$

[E.g. 3]

①a water tank saves 10L of water originally and enters 5L of water per minute.

②a water tank saves 10L of water originally, enters 5L of water per minute and pumps 2L of water per minute synchronously.

③a water tank saves 10L of water originally and pumps 2L of water per minute.

In this example, teachers explain the process of setting up the model ① and ②, students completes the process of model ③. The structure model is:

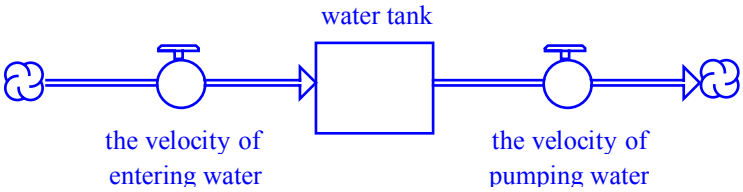

Figure 3(a) water tank structure model (1)

2.1.2 The brief introduction of the action connector and the converter

The action connector shows the relation of influence, if $x \rightarrow y$, that means that $y = f(x)$, but it can't point to the stock. And the converter can enact a value but it can not accumulate as the stock.

[E.g. 4]

①a water tank saves 10L of water originally and pumps 20% of the water tank's water quantity per minute.

②a water tank saves 10L of water originally, enters 5L of water per minute and pumps 20% of the water tank's water quantity per minute synchronously.

In this example, Teachers explain the setting up the model process of ①, students completes the process of ②. The structure model is such that

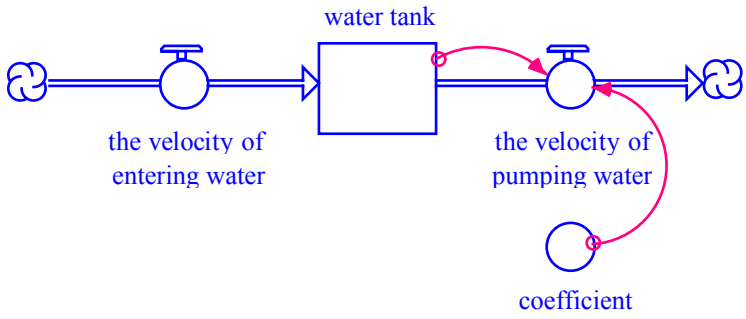

Figure 3(b) water tank structure model (2)

After doing these exercises, students learn how to use the software and set up a model for the first step.

2.2 Basic models of chemical equation calculation (students' handout, Lesson two)

There are three kinds of basic types of the chemical equation calculation: the direct calculation, the excessive calculation and the dividing to steps calculation. Their corresponding STELLA structures are illustrated as follows.

2.2.1 The direct calculation model

[E.g. 5] magnesium reacts with plenteous hydrochloric acid

The thinking of setting up model is: We act the amount-of-substance of magnesium and H_2 as a stock. In each infinitesimal time, it will consume the infinitesimal magnesium. If only calculating the yield only (that means neglecting the factor of reaction time), we can suppose the velocity of reaction (the flow) was symmetrical, its value is 0.001 mol/s might as well. At the same time, basing on the chemical reaction equation ($Mg + 2HCl = MgCl_2 + H_2\uparrow$), when consumes definite amount-of-substance of Mg, it can produce equivalent amount-of-substance of H_2, So the consuming velocity of Mg is equal to the producing velocity of H_2 (Fig. 4).

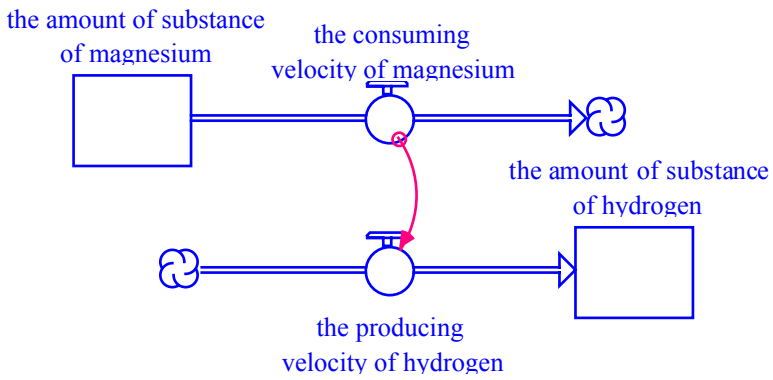

Figure 4(a) the structure model of magnesium reacting with plenteous hydrochloric acid (1)

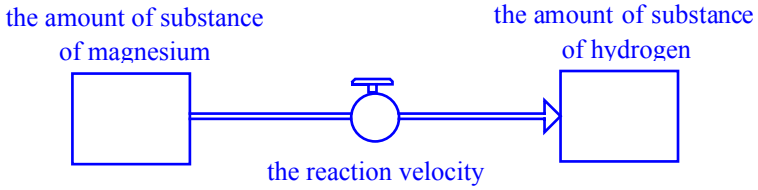

Figure 4(b) the structure model of magnesium reacting with plenteous hydrochloric acid (2)

Finally, we endow with original value for the stock: the amount-of-substance of magnesium is *1mol* and the amount-of-substance of hydrogen is *0mol*. Applying the "STELLA", we can obtain the graphs of the amount-of-substance of magnesium and hydrogen change during the reaction (Fig. 5).

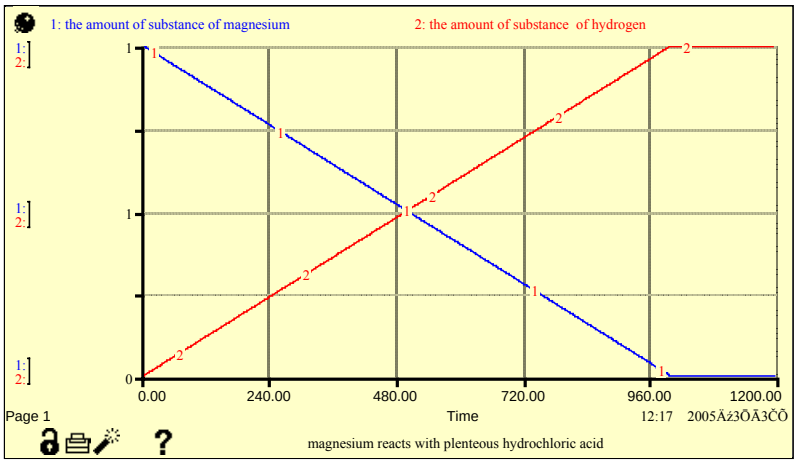

Figure 5

In the above figure, the red line shows the amount-of-substance of magnesium variety and the blue one shows the amount-of-substance of hydrogen variety. Magnesium consumes completely and 1mol hydrogen produces at the same time when 1,000s, which inosculates our expectation accurately. So we can research reaction process from the dynamic state by using the software "STELLA" as experiment terrace.

2.2.2 The excessive calculation model

[E.g. 6] magnesium reacts with hydrochloric acid (need to judge which reactant is excessive)

Because of the quantity of reactant not know, we must plus a judgment program: When magnesium and hydrochloric acid are both exist, the reaction take place, otherwise stop. So we endow with the value for the consuming velocity magnesium is that *If (the amount-of-substance of magnesium >=0.001 and the amount-of-substance of hydrochloric acid >=0.001) 0.001 else 0*.

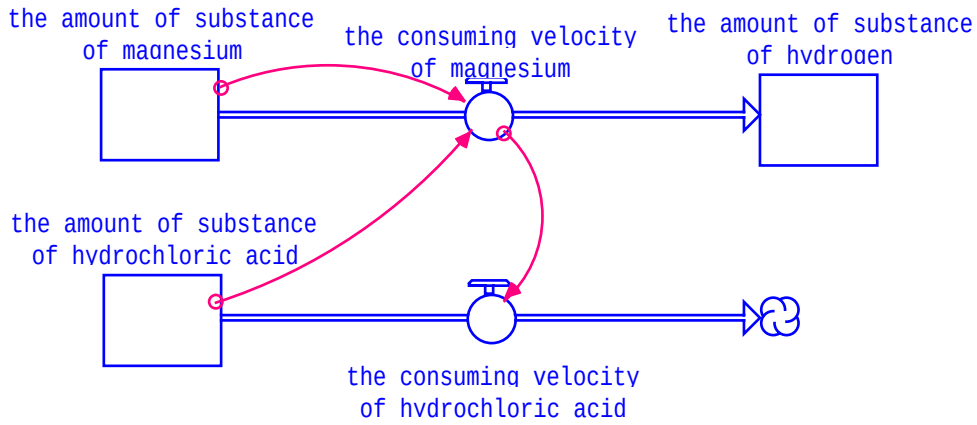

Figure 6 the structure model of magnesium reacting with hydrochloric acid (need excessive judgment)

Next we endow with original value for the stock: the amount-of-substance of magnesium is *1mol*, the amount-of-substance of hydrogen is *0mol*and the amount-of-substance of hydrochloric acid is *0.8mol*, and we can obtain the graphs of the amount-of-substance of magnesium, hydrogen and hydrochloric acid change during the reaction (Fig. 7).

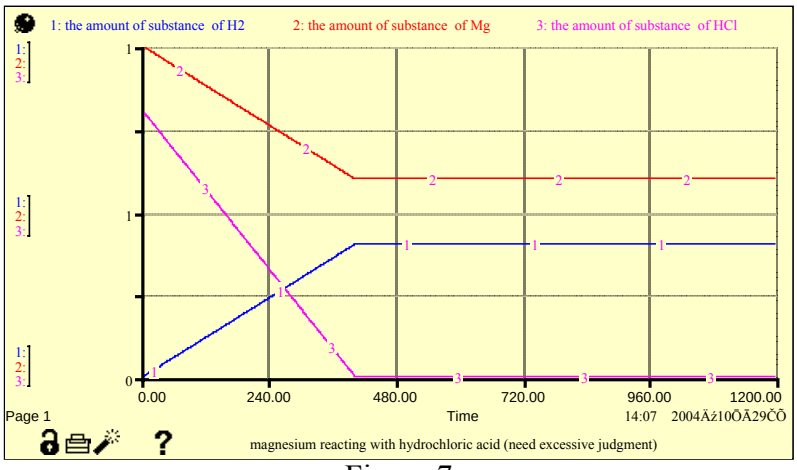

Figure 7

Figure 7 shows that in the 0-400s, the amount-of-substance of hydrogen (blue line) changes from 0mol to 0.4mol; the amount-of-substance of hydrochloric acid (pink line) changes from 0.8mol to 0mol; the amount-of-substance of magnesium (red line) changes from 1mol to 0.6mol.

2.2.3 The dividing to steps calculation model

[E.g. 7] carbon reacts with oxygen under high temperature

This process may have 4 equations as shown follow: (ignoring the reaction condition)

$C + O_2 = CO_2$ ①

$2C + O_2 = 2CO$ ②

$2CO + O_2 = 2CO_2$ ③

$CO_2 + C = 2CO$ ④

However, the independent equations only have 2 actually (③ =①×2-②, ④ =②-①), so we select two of them such as ① and ②.

There are 5 instances as shown follow when the reactant ratio changes:

(1) $n(C)/n(O_2)$ =1:1, accurately reacts by ① and no reactant is remained;

(2) $n(C)/n(O_2)$ =2:1, accurately reacts by ② and no reactant is remained;

(3) $n(C)/n(O_2)$ <1, reacts by ①, O_2 is excessive and remained;

(4) $n(C)/n(O_2)$ >2, reacts by ②, C is excessive and remained;

(5) 1< $n(C)/n(O_2)$ <2, reacts by ① and ②, no reactant is remained.

(1), (2) above can be solved by the direct method; (3), (4) can be done by the excessive judgment method; and (5) can be done by dividing to steps method. We endow with the value for the volume of carbon monoxide is that *if (n C<0.001 and n O_2>=0.0005 and n CO>=0.001) 0.001 else 0*.

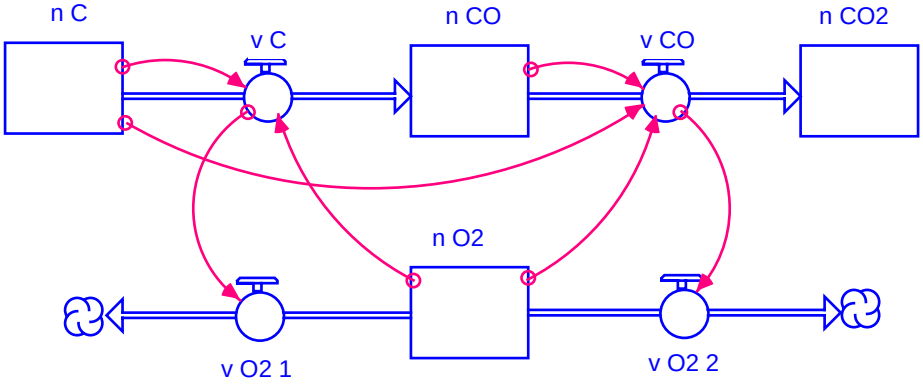

Figure 8 the structure model of carbon reacts with oxygen (dividing to steps)

Next we endow with original value for the stock: the amount-of-substance of carbon is *1mol*; the amount-of-substance of oxygen is *0.6mol*; the amount-of-substance of carbon monoxide is *0mol*; and the amount-of-substance of carbon dioxide is *0mol*. we can obtain the graphs of the amount-of-substance of carbon, oxygen, magnesium, carbon monoxide and carbon dioxide change during the reaction (Fig. 9).

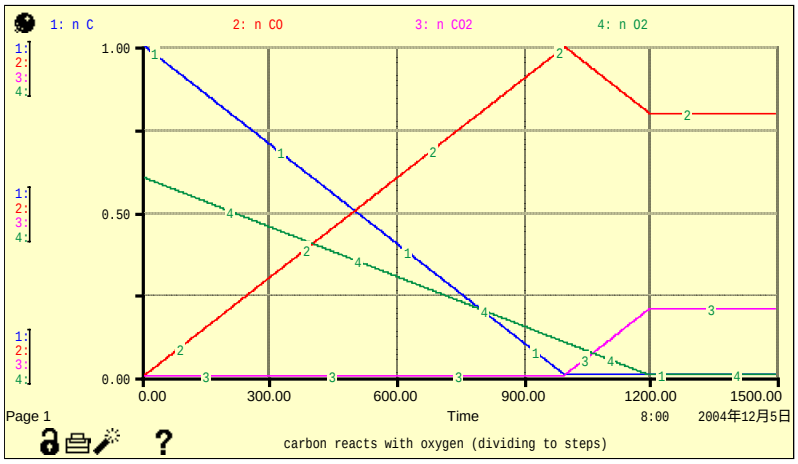

Figure 9

It shows that in the 0-1000s, the amount-of-substance of carbon monoxide (red line) changes from 0mol to 1mol; the amount-of-substance of carbon (blue line) changes from 1mol to 0mol; the amount-of-substance of oxygen (green line) changes from 0.6mol to 0.1mol, and in the 1000-1200s, the amount-of-substance of carbon monoxide changes from 1mol to 0.8mol; the amount-of-substance of oxygen changes from 0.1mol to 0mol; the amount-of-substance of carbon dioxide (pink line) changes from 0mol to 0.2mol.

[Practice] Complete the structure model and the endowing value belows:

(1) The reaction equation is: $2NO + O_2 = 2NO_2$ ⑤, need excessive judgment, the consuming velocity of nitrogen monoxide is 0.002mol/s.

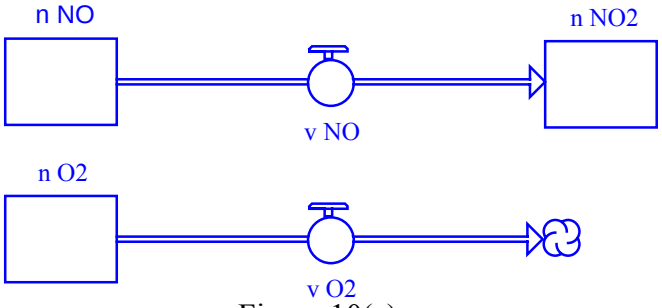

Figure 10(a)

v NO: _____; v O_2: _____.

(2) The reaction equation is: $3NO_2 + H_2O = 2HNO_3 + NO$ ⑥, the enough water and the consuming velocity of nitrogen dioxide is 0.003mol/s.

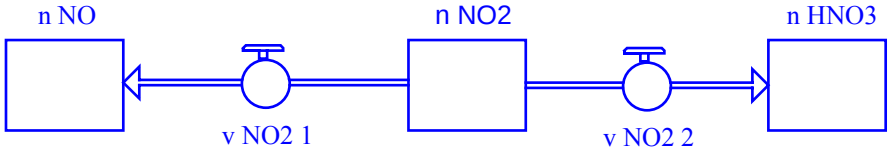

Figure 10(b)

v NO_2 1: _____; v NO_2 2: _____.

2.3 The mix of nitrogen oxygen compound and oxygen dissolving to water calculation (1) (Lesson three)

[Experiment] Set upside down a measuring cylinder filling with 40mL NO in the sink. And inject 10mL oxygen in it each time (4 times, total 40mL). Then observe the

liquid face change inside the measuring cylinder.
[Teacher] Ask students to analyze the phenomena and give an explanation.
[Students answer; Teacher summarizes]
[Teacher] How to create a corresponding model for deeper study?
[Students] Complete the whole model creating process.

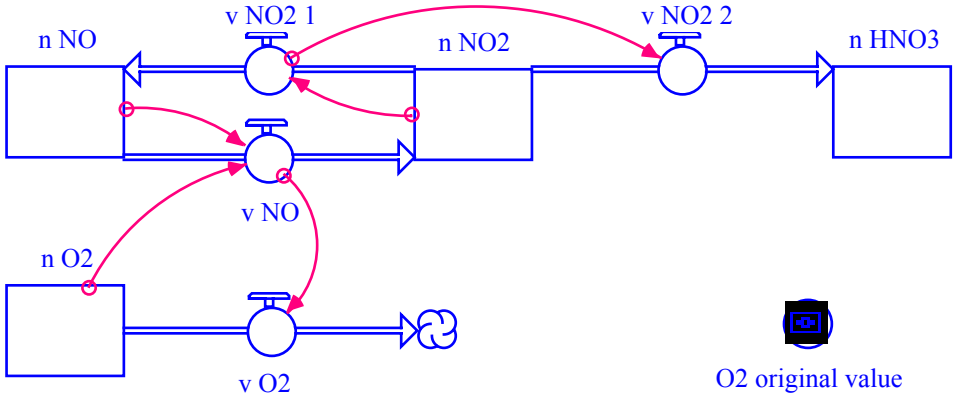

Figure 11 the direct structure model of NO mix with oxygen to dissolve into the water
[Students] Ask students to fill in the following blanks with the exporting data.

Table 1

Experiment serial number	1	2	3	4	5	6	7	8	9
original V NO(mL)	40	40	40	40	40	40	40	40	40
original V O_2(mL)	0	5	10	15	20	25	30	35	40
final V NO(mL)	40	33.3	26.7	20	13.3	6.67	0	0	0
final V NO_2(mL)	0	0	0	0	0	0	0	0	0
final V O_2(mL)	0	0	0	0	0	0	0	5	10

[Students] Construct the graphs according Table 1.

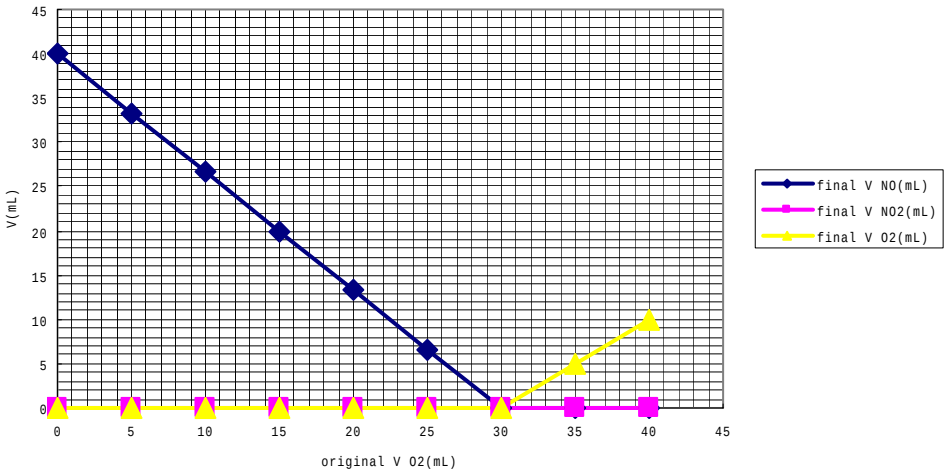

Figure 12
[Teacher] What conclusion can we get from the graphs?
[Students answer] NO reacts with O_2 by volume ratio of 4:3 fitly.
[Teacher] Can we write an equation according to the result? (A student writes it on the

blackboard)

[Teacher] What is the relation of this equation ($4NO + 3O_2 + 2H_2O = 4HNO_3$ ⑦) and ⑤⑥?

[Students answer]

[Teacher] How can we prove it?

[Student] Complete the whole creating model process.

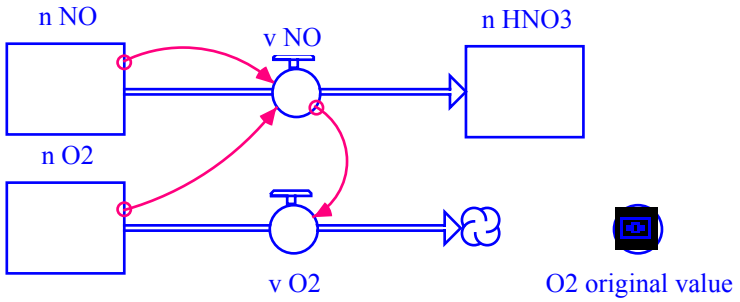

Figure 13 the structure model of NO mix with oxygen to dissolve into the water (combination)

[Teacher summarizes]

[Practice] Calculate the remanent volume after each operation in the experiment according to the equation ⑦.

2.4 The mix of nitrogen oxygen compound and oxygen dissolving to water calculation (2) (Lesson four)

[Teacher] Apply the direct structure model of NO mix with oxygen to dissolve into the water (Fig. 11), and endow with original value for the stock: the volume of nitrogen dioxide (V NO_2, the rest may be deduced by analogy) is *0-100mL*; the volume of oxygen is *100-V NO_2*; and the volume of nitrogen monoxide is *0*. Run "STELLA" and record the data, then fill in the following blanks.

Table 2

Experiment serial number	1	2	3	4	5	6	7	8	9	10	11
original V NO_2(mL)	100	90	80	70	60	50	40	30	20	10	0
original V O_2(mL)	0	10	20	30	40	50	60	70	80	90	100
final V NO(mL)	33.3	16.7	0	0	0	0	0	0	0	0	0
final V NO_2(mL)	0	0	0	0	0	0	0	0	0	0	0
final V O_2(mL)	0	0	0	12.5	25	37.5	50	62.5	75	87.5	100

[Students] Construct the graphs according Table 2.

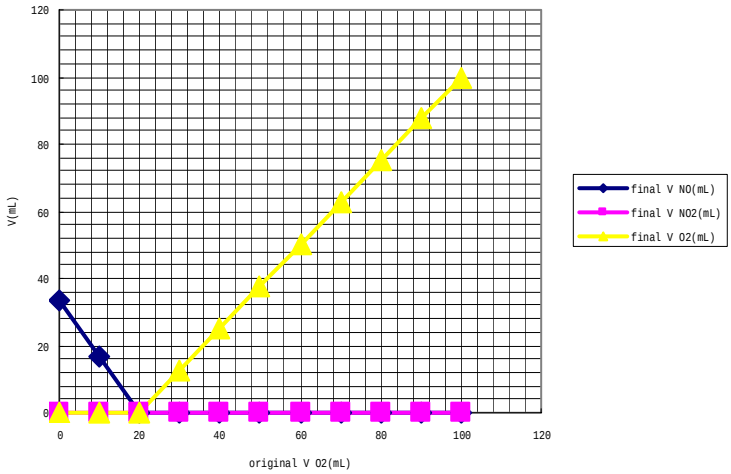

Figure 14

[Students summarize] NO_2 reacts with O_2 by volume ratio of 4:1 fitly.

[Students] Write the combination equation. ($4NO_2 + O_2 + 2H_2O = 4HNO_3$ ⑧)

[Students] Creat the dividing to steps model according to the equation ⑧ and ⑥, and validate them.

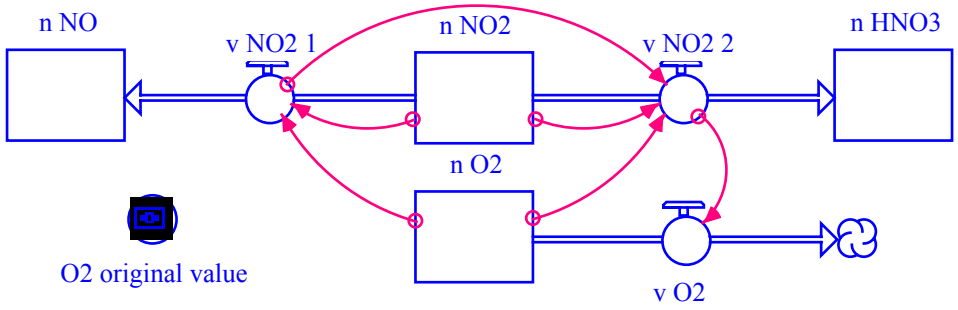

Figure 15 the structure model of NO_2 mix with oxygen to dissolve into the water (combination and dividing to steps)

[Teacher summarizes]

[Practice]

(1) Calculate the original value of V NO_2 when 10mL gas remains in the measuring cylinder.

(2) Choose a chemical equation calculation example, and complete the whole creating model process by "STELLA".

3 Conclusion

Comparing with the traditional methods of teaching the chemical equation calculation in high schools, our innovative way based on system thinking has some remarkable advantages:

(1) Students could have a basic understanding of system thinking. Teachers and students can use models to make tests about theories and observe the results together, and learn what would happen if the existing assumption or situation has changed, so that students can learn in a grand environment by discussion. The large number of

exercises can be replaced by active and interactive activities. With computer simulated tests, instead of spending much time on memorizing theories ,students can have more time to think deeply about what they have learned for a better understanding,. It is much more possible for students to make exploration in depth , express their own ideas, and then correct, perfect and eventually demonstrate their own ideas through simulation tests. Such a learning process can help students to inspire their inner energy to control themselves actively, and to experience the sense of achievement,so that they can develop tap on their “curiosity” freely and find the scientific answers, and study hard to meet with success. These courses mainly introduce the application in the chemistry teaching, however, it is pleasantly surprised that students have much practice in other subjects after school, and some examples are listed as shown follows:

[E.g. 8] At the high sky apart 1,000m from the ground, a object (mass of 1kg) falls form stillness. In addition to gravitation, it also resistant by the air, which value equals to 0.001multiply the square of the falling velocity (unit: N). Calculate the velocity and time when it arrives the ground.

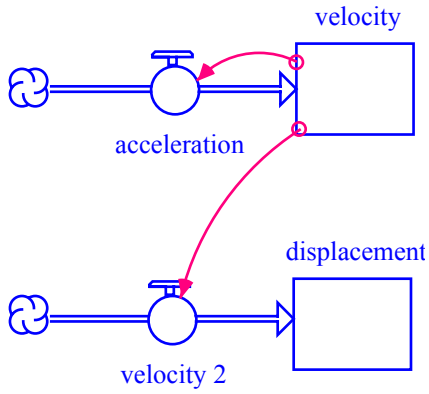

Figure 16 the falling object structure model

[E.g. 9] A man borrows 100,000 dollars from the bank for buying house (the lending rate is 5.31% per year and keeps immovability), and he chooses the mode of the equal sum monthly (the returning time is 15 years). Calculate the sum of pay per month and the total interest.

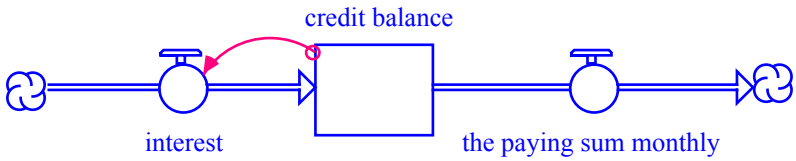

Figure 17 the returning loan structure model

(2) After the teaching, students become interesting in study and they can regard themselves an integral part of the system. Some events may seem unpredictable when viewed locally, but their mutual relations can made clear and therefore they can be understood when viewed in a broader system. Through conversations aimed to foster the ability of thinking and intensive study, students will be acquired with the basic ability to adapt to external demand and changes in opportunities, and changed in their way to respond to the surrounding world. This can build up their confidence and boldness for the future, stimulate their enthusiasm in study and coordinate their

effective actions, thus improving their achievements at the same time.

(3) Along with the advance of society and growth of students, teachers 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 off 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 [3]. Such as the author and students can research on chemical equilibriums in electrolyte solution with system thinking, and one example is shown as follow (Fig.18).

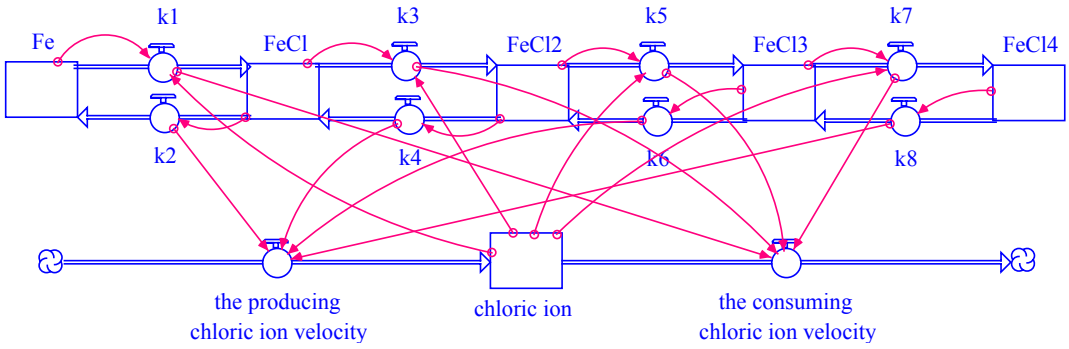

Figure 18 the Fe^{3+}-Cl^- system structure model

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