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Strengthening the Creative Ability and Independence Learning of College Students Based on Self-Perception Theory—Taking Gibbs-Duhem Equation as an Example

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Abstract

The essence of education is to educate people, and the main goal of education is to educate on people how to think and make people not only have perfect personality, but also have strong learning ability. The teacher is the best person to complete education. Based on self-perception theory, the teacher guided students to finish the derivation of the Gibbs-Duhem (G-D) equation in order to strengthen the students' internal incentive. With a new establishment of partial molar quantity and set formula, students promoted their thinking ability and solidified internal incentive with a sense of achievement. The logical establishment process of the G-D equation was used to supplement this currently widely used derivation process by heuristic teaching method. The system conditions to which the G-D equation applied and the nature of its zero-degree homogeneous function were the key to understanding the derivation process. The derivation was carried out along the route of induction-deduction-induction, highlighting the training of thinking. Students' internal incentive not only strengthened their innovative ability, but also provided the conditions for their future success, which played a very important role in serving the society.

Keywords

Self-Perception Theory, Internal Incentive, Gibbs-Duhem Equation, Innovative Thinking

1. Introduction

In today's severe pandemic situation, it is very important to train medical talents in universities, and it is even more commendable to develop students' innovative thinking through education. The urgent scrutiny of undergraduate science, technology, engineering, and mathematics (STEM) education has recently caused more and more research interesting for educators, education managers and policymakers in government departments, because the STEM is to meet the requirements of economic development for talents. Therefore, this requirement has argued that the faculty needs to be more active and responsible for being in research of knowledgeable of theories of learning, student learning experience, and research-based instructional strategies. Education is a social activity in which human beings purposefully (consciously) cultivate people (strictly, there is no education in the animal kingdom), and education must be acquired after birth, relative to congenital, which is also a way of inheriting culture, inheriting production and social life experiences (Erbil & Kocabaş, 2020), for example, children will suck milk when they are born, which is innate rather than education. Broad education includes social education, school education, and family education, for example, if there are some men walking together, one of them is bound to be good enough to be my teacher, and talking with you for one moment is much better than reading books for ten years, etc. Narrow education usually refers to school education, where educators educate students in an organized, planned, and purposeful way according to the development law of students' physical and mental health, and promote them to develop along the desired direction on the basis of developing needs required by industrial society, knowledge society and post-knowledge society. More narrowly defined education is moral education (such as ideological and moral courses), and from an individual perspective, education is the process of individual learning and development. In summary, education is a practical activity that promotes individual socialization and social individualization under a certain social background, and the opposite of individual socialization is individual liberalization (learning a lot of social norms), and social individualization is the individualized expression of the common social norms on individuals.

Therefore, the essence of education is to educate people, which is the fundamental feature of education that differs from other things and the qualitative regulation of education. Three main characteristics are as follows: Education is a kind of conscious social activity unique to mankind (purpose); education is an activity in which human beings consciously transfer social experience (sociality); education is a social practice activity that directly cultivates people (education) (Erbil & Kocabaş, 2020; Tasdemir & Gazo, 2020). The ultimate goal of education is to educate people, and it is more important to teach students how to think, that is to say, good thinking methods can help them succeed, which will be beneficial to the society. Education is also a kind of imparting of thinking, and people have another kind of thinking trend because of their own ideology. Then, education should be taught to people with the most objective and impartial conscious thinking. People's thinking will not be too deviant and gradually become mature and rational due to the richness of thinking. From this, we can move towards the most rational self and have the most correct thinking cognition.

Teaching is the basic way to carry out the policy of education, implement the comprehensive development of education and realize the purpose of education (Tasdemir & Gazo, 2020). Teaching is the most effective form of disseminating systematic knowledge and promoting the development of students, and it is also a powerful means of reproducing social experience, adapting and promoting social development. Teaching is an important part of cultivating students' all-round development of personality by providing a scientific basis and practice. Teaching is also one of the ways of moral education, aesthetic education, sports, etc., and intellectual education is the main task of teaching, which also needs to be developed and consolidated through extracurricular activities.

Teachers are the organizers of the educational process and play a leading role in all educational activities. As an independent social individual, teachers and students are a friendly and helpful relationship of friends (Jean-Jacques Rousseau, 1712-1778, French Enlightenment Thinker, John Dewey, 1859-1952, American pragmatism educator, both fully affirmed the student's dominant position (Taylor, 2020; Bender, 2020). In order to improve the teaching effect, teachers should give active guidance to students. However, in most schools, teaching is still the traditional way of "preaching, teaching and solving doubts". As for the teaching content, it remains unchanged for many years, and the teaching method without a heuristic function is old too. For example, in physical chemistry textbooks at home and abroad (Atkins & De Paula, 2014; Fu et al., 1990; Shao et al., 2017), Gibbs-Duhem (G-D) equation is a traditional reasoning process. For partial molar quantity, it is still a function of temperature, pressure and composition. This property has not been deeply explained and applied, and it has not been used in the derivation of the set equation and the G-D equation. Therefore, for researchers and teachers, it is very important to update teaching contents and methods, stimulate students to think positively and improve their thinking ability.

2. The Role of Self-Perception Theory on the Learning

Self-perception theory divides the reasons for people's study behaviors into two dimensions, namely, self-perceived external motivation and self-perceived internal motivation. There are strong and weak points in each dimension, so there are four typical situations, i.e. external excitation is strong and internal excitation is weak, external excitation is weak and internal excitation is strong, both external excitation and internal excitation are weak, both external excitation and internal excitation are strong. In this article, we only discuss this situation: external excitation is weak and internal excitation is strong due to the most closely relations to the learning positive attitude and effect. Of course, the length limitation is also a factor.

In this situation, students have a higher interest in learning by themselves, moreover, they have a deeply pleasant experience in learning activities, but there is no obvious or strong external incentive to promote students' learning, whether material or social-emotional incentive. According to the self-perception theory, students' mentality is also stable and balanceable at this time, because students can attribute their own reasons of learning motivation to their inner interests, rather than any external incentives. For example, in the story of "bore a hole on the wall to make use of the neighbour's light to study", in Han Dynasty, Heng Kuang (also called as Gui Zhi, born in the late Western Han Dynasty, a Confucian scholar in the Western Han Dynasty, and a famous prime minister) was very diligent and eager to learn. Because his family was very poor, he had to do a lot of work during the day to earn money. Only at night can he study with peace of mind. However, he couldn't afford candles, and as soon as it got dark, he couldn't read books. Heng Kuang felt very painful for this wasted time. His neighbor was very rich. At night, candles were lit in several rooms to brighten all rooms. One day, Heng Kuang got up his courage and said to his neighbor, "I want to study at night, but I can't afford candles. Can I borrow an inch of your house?" This neighbor had always looked down on people who were poorer than their family, so he sarcastically said, "If you are too poor to buy candles, why should you read?" Heng Kuang was very angry, but he was even more determined to read the book well. When Heng Kuang returned home, he quietly and secretly bored a small hole in the wall, and the candlelight of the neighbor's house passed through the hole. Taking advantage of this dim light, he read hungrily, and gradually finished all the books. He became a famous scholar when he grew up. Obviously, when Heng Kuang was studying, there was no strong external incentive, neither material reward nor emotional praise. The reason why he could persist was that he could experience strong and lasting fun in the process of reading. His mentality must also be balanced, because he could clearly attribute his learning behaviors to the pleasure of reading, rather than the reward or praise given by others.

Therefore, in the study process, firstly, the thought education of students is indispensable, why to learn, for whom to learn, this is the first thing to solve. Secondly, teachers guide how to learn by setting a few small goals that can be easily achieved, so that students can gain a sense of accomplishment and increase their confidence in learning. Finally, they should change old thinking habits, innovate their thinking way through logical thinking training, and increase practical training and pay attention to the practice process, and improve their ability to analyze and solve problems. In summary, student's own internal incentive in learning and logical thinking ability is key to obtain future success.

3. A New Insight of Gibbs-Duhem Equation

The main teaching mode is still the transfer-acceptance type in China. The advantage is that it can present fully the leading role of the teacher and enable students to obtain a large amount of systematic and scientific knowledge in a short time. The disadvantage is that it is not easy to stimulate the initiative and enthusiasm of students. Although the teacher is the instructor and the student is the recipient, it is not a simple indoctrination relationship, that is to say, i tell you what you listen to. Teachers should mobilize students' initiative and enthusiasm, guide them to master scientific knowledge consciously and improve their ability to analyse and solve problems through independent thinking, active exploration and lively learning.

Exemplary teaching is one of the generally adopted better forms for learning basic knowledge, embodying the unity of problem teaching and system learning, and the unity of mastering knowledge and developing ability (Martin Wagenschein, 1896-1988, Famous German Educator and Practitioner (Wagenschein, 2010). The basic process is to exemplarily clarify the individual case—the category case—to exemplarily master the principle of law—to grasp the methodological significance of the law, and to apply the training of the law. Example teaching can cultivate students' good thinking quality in teaching, strengthen the training of scientific thinking methods, and use heuristics method to arouse students' positive and active thinking (Atkins & De Paula, 2014). In particular, the training of thinking mode is crucial to the future success of college students, because good thinking ability can ensure good lifelong learning ability. With the popularization of the concept of lifelong learning, it is more urgent for students to master lifelong learning ability. Therefore, only when students master this learning ability can they make greater achievements in society. Thinking refers to thinking activities based on scientific principles and concepts to solve problems, also known as logical thinking, including analysis and synthesis, comparison and classification, abstraction and generalization, systemization and concretization. Analysis (deduction) and synthesis (induction) are the basic processes of logical thinking, and the ultimate goal is to acquire a stronger creative thinking ability and enhance lifelong learning ability so as to better serve society. It is also expected to provide a reference for teachers' teaching methods and teaching idea to meet the requirements of modern teaching education.

The establishment process of Gibbs-Duhem (G-D) equation is an example (Shao et al., 2017) of the application of logical thinking (induction-deduction-induction). Through heuristic teaching methods, students' thirst for knowledge is stimulated, creative motivation is cultivated, students' enthusiasm and initiative in learning is mobilized, and the purpose is to improve the ability of their creative thinking and strengthen their internal incentive in the process of study.

Taking the problem-oriented as the main line of the new analysis process, firstly, the existing problems and difficulties in study are analyzed, and the characteristics of partial molar quantity is deeply analyzed. Secondly, according to the key point that partial molar quantity is still a function of temperature, pressure and composition, G-D equation is re-deduced. Finally, the system conditions to which G-D equation applied and the nature of its zero-degree homogeneous function were the key to understand the derivation process.

1) Questions

a) The current difficulty is that students cannot clearly understand the definition of partial molar quantities.

b) In commonly used textbooks, partial molar quantity is still a function of temperature, pressure and composition, but this problem has been simplified, and there is no rigorous and logical derivation process resulting in the difficult understanding.

c) The third difficulty is that students do not have a good understanding of the mathematical principle of partial mole quantities and the relationship of between set formula and partial molar quantity.

2) Measures

a) A new derivation and re-establishment of partial molar quantity.

b) A logical thinking training of induction-deduction-induction.

c) Stating the shortcomings in the current textbooks with the compared method.

3) Results

A new insight of partial molar quantity with the essential characteristics of zero-degree homogeneous function inspires students to think divergently and innovatively.

3.1. The Re-Establishment of Partial Molar Quantity

Partial molar quantity is a very important thermodynamic concept, in a homogeneous and multi-component macro-system with variable composition, when constant temperature ($dT = 0$) and constant pressure ($dP = 0$), and the amount of substance in all components except one component B is constant, the change of capacity property (extension quantity) X caused by the increase of one mole of component B is called as partial molar quantity X_B.

Here, it should be emphasized that the assumed model is a very large macro system, an increase of 1 mole of any substance will not change the ratio of all substances in this system, which is the premise of the existence of the concept of partial molar quantity:

$$X_B = \left(\frac{\partial X}{\partial n_B}\right)_{T,P,n_{C\neq B}} \tag{1}$$

These capacity properties (X) include volume (V), enthalpy (H), thermodynamic energy (U), etc., which also indicate that the thermodynamic property is a function of temperature, pressure, the amount of substance ($n_1,\cdots,n_m$) in the components and the ratio (composition) (such as $n_1 : n_2$) between the components. But partial molar quantity is the strength property (rate of change), and is also affected by temperature, pressure, the amount of substance in components and the ratio between the components, or it is a function of these factors, that is to say, $X_B = f\left(T,P,n_1,\cdots,n_m\right)$.

If all components in the system increased or decreased by the same multiple (i.e. the ratio is constant), the partial molar quantity will not be affected as long as other factors remain unchanged. For a macro system, adding a certain amount of substance is still a macro system, which would not change the essential nature of partial molar quantity, because it is a ratio of the capacity property to the amount of substance-a rate of change, and it is an increase in relativity rather than absolute quantities. In other words, the partial molar quantity of any substance is mainly affected by the relative amount of different substances. As long as the ratio between any two matters changes, this partial molar quantity will change. Therefore, partial molar quantity is a zero-degree homogeneous function (Equation (2)), which is an essential characteristics of partial molar quantity, and it is also a prerequisite for the generation of set formula, rather than a limiting condition. Obviously, the composition is an important factor that affects partial molar quantity:

$$X_B\left(an_1, an_2, \cdots, an_m\right) = a^n X_B\left(n_1, n_2, \cdots, n_m\right); n = 0 \tag{2}$$

In addition, the constant T and P is a prerequisite for partial molar quantity too.

Taking the homogeneous system of $1, 2, 3, \cdots, m$ components as an example, the generation of this set formula is derived as follows.

The function of any capacity property can be expressed in Equation (3).

$$X = f\left(T, P, n_1, \cdots, n_m\right) \tag{3}$$

To find exact differential:

$$\mathrm{d}X = \left(\frac{\partial X}{\partial T}\right)_{P,n} \mathrm{d}T + \left(\frac{\partial X}{\partial P}\right)_{T,n} \mathrm{d}P + \left(\frac{\partial X}{\partial n_1}\right)_{T,P,n_{i\neq 1}} \mathrm{d}n_1 + \cdots + \left(\frac{\partial X}{\partial n_m}\right)_{T,P,n_{i\neq m}} \mathrm{d}n_m \tag{4}$$

When T and P are all constants, moreover, the ratio does not change ($n_1 : n_2 : \cdots : n_m = C$, constant),

$$X = \int_0^x \mathrm{d}X = \int_0^{n_1} X_1 \mathrm{d}n_1 + \cdots + \int_0^{n_m} X_m \mathrm{d}n_m = \sum\nolimits_{i=1}^{m} X_i n_i \tag{5}$$

where i represents the components from 1 to m). Set Formula (5) contains some characteristics, and thinking of induction is as below:

Firstly, the set formula starts from Equations (3) and (4), that is, from the investigation of influencing factors, when integrating, some conditions are added or considered (constant T and P, $n_1 : n_2 : \cdots : n_m = C$), indicating that the generation of the set formula is under specific conditions, that is, the generation of the set formula is considered only after the special situation is obtained. Of course, these conditions are consistent with the requirements of the conditions when defining partial molar quantity, moreover, the reason why integration is possible is that partial molar quantity of each substance is a fixed value by default due to a great macro system. The result is that this capacity property X is the sum of partial molar quantities of all components in the system.

Secondly, X is the state function (thermodynamic property) of the system, which is general and universal and affected by T, P, n_1, n_2, …, and C.

Therefore, the applicability of X function goes from special case to generality, presenting the characteristics of induction. Obviously, in $X = \sum_{i=1}^{m} X_i n_i$, the exact differentiation of X can be performed again to investigate the influence of various factors. However, at present, most textbooks in China are simply deduced. Here, the partial molar quantity as a strength quantity is still affected by some factors such as temperature, pressure, and composition, etc.

The derivation of the G-D equation is as follows.

The set Formula (5) is exactly differentiated, and thinking of deduction is also expanded to specific case.

$$\mathrm{d}X = \sum_{i=1}^{m} X_i \mathrm{d}n_i + \sum_{i=1}^{m} n_i \mathrm{d}X_i \tag{6}$$

The partial molar quantity X_i can be further differentiated

$$\begin{aligned}\sum_{i=1}^{m} n_i \mathrm{d}X_i = \sum_{i=1}^{m} n_i \left(\frac{\partial X_i}{\partial T}\right)_{P,n} \mathrm{d}T + \sum_{i=1}^{m} n_i \left(\frac{\partial X_i}{\partial P}\right)_{T,n} \mathrm{d}P \\ + \sum_{i=1}^{m} n_i \sum_{j=1}^{m} \left(\frac{\partial X_i}{\partial n_j}\right)_{T,P,n\neq n_j} \mathrm{d}n_j\end{aligned} \tag{7}$$

In addition,

$$\begin{aligned}\sum_{i=1}^{m} n_i \left(\frac{\partial X_i}{\partial T}\right)_{P,n} &= \sum_{i=1}^{m} n_i \left(\frac{\partial}{\partial T}\left(\frac{\partial X}{\partial n_i}\right)_{T,P,n_{j\neq i}}\right)_{P,n} \\ &= \frac{\partial}{\partial T}\left(\sum_{i=1}^{m} n_i \left(\frac{\partial X}{\partial n_i}\right)_{T,P,n_{j\neq i}}\right)_{P,n} = \left(\frac{\partial X}{\partial T}\right)_{P,n}\end{aligned} \tag{8}$$

$$\text{Similarly: } \sum_{i=1}^{m} n_i \left(\frac{\partial X_i}{\partial P}\right)_{T,n} = \left(\frac{\partial X}{\partial P}\right)_{T,n} \tag{9}$$

Substituting Equations (8) and (9) into Equation (7)

$$\sum_{i=1}^{m} n_i \mathrm{d}X_i = \left(\frac{\partial X}{\partial T}\right)_{P,n} \mathrm{d}T + \left(\frac{\partial X}{\partial P}\right)_{T,n} \mathrm{d}P + \sum_{i=1}^{m} n_i \sum_{j=1}^{m} \left(\frac{\partial X_i}{\partial n_j}\right)_{T,P,n\neq n_j} \mathrm{d}n_j \tag{10}$$

Substituting Equation (10) into Equation (6)

$$\mathrm{d}X = \sum_{i=1}^{m} X_i \mathrm{d}n_i + \left(\frac{\partial X}{\partial T}\right)_{P,n} \mathrm{d}T + \left(\frac{\partial X}{\partial P}\right)_{T,n} \mathrm{d}P + \sum_{i=1}^{m} n_i \sum_{j=1}^{m} \left(\frac{\partial X_i}{\partial n_j}\right)_{T,P,n\neq n_j} \mathrm{d}n_j \tag{11}$$

Because Equation (4) was obtained from the exact differentiation of $X = f(T, P, n_1, \cdots, n_m)$, then, Equation (4) can be simplified into (12) as follows:

$$\mathrm{d}X = \sum_{i=1}^{m} X_i \mathrm{d}n_i + \left(\frac{\partial X}{\partial T}\right)_{P,n} \mathrm{d}T + \left(\frac{\partial X}{\partial P}\right)_{T,n} \mathrm{d}P \tag{12}$$

Comparing (11) with (12):

$$\text{Obtained: } \sum_{i=1}^{m} n_i \sum_{j=1}^{m} \left(\frac{\partial X_i}{\partial n_j}\right)_{T,P,n\neq n_j} \mathrm{d}n_j = 0 \tag{13}$$

Equation (13) can be considered as another form of G-D equation too (Fu et al., 1990; Yang & Wu, 2003), when the change of temperature and pressure is considered. This equation is no different with the current common form in essence.

The result is further proved from the characteristic that the partial molar quantity is a homogeneous function of zero-degree.

Equation (13) can further be changed into:

$$\begin{aligned}\sum_{i=1}^{m} n_i \sum_{j=1}^{m} \left(\frac{\partial X_i}{\partial n_j}\right)_{T,P,n\neq n_j} \mathrm{d}n_j &= \sum_{i=1}^{m} n_i \sum_{j=1}^{m} \left[\frac{\partial}{\partial n_j}\left(\frac{\partial X}{\partial n_i}\right)_{T,P,n\neq n_i}\right]_{T,P,n\neq n_j} \mathrm{d}n_j \\ &= \sum_{i=1}^{m} n_i \sum_{j=1}^{m} \left[\frac{\partial}{\partial n_i}\left(\frac{\partial X}{\partial n_j}\right)_{T,P,n\neq n_j}\right]_{T,P,n\neq n_i} \mathrm{d}n_j = \sum_{j=1}^{m} \sum_{i=1}^{m} n_i \left[\frac{\partial X_j}{\partial n_i}\right]_{T,P,n\neq n_i} \mathrm{d}n_j\end{aligned} \tag{14}$$

Because the partial molar quantity is a zero-degree homogeneous function, i.e. $\sum_{i=1}^{m} n_i \left[\frac{\partial X_j}{\partial n_i}\right]_{T,P,n\neq n_i} = 0$, then, $\sum_{i=1}^{m} n_i \sum_{j=1}^{m} \left(\frac{\partial X_i}{\partial n_j}\right)_{T,P,n\neq n_j} \mathrm{d}n_j = 0$.

G-D equation is the inevitable result of zero-degree homogeneous function of partial molar quantity, which is consistent with the essential property of partial molar quantity because when defining partial molar quantity, one of the required conditions is constant temperature and pressure.

Equation (10) can be further simplified to (15) after introducing (13)

$$\sum_{i=1}^{m} n_i \mathrm{d}X_i = \left(\frac{\partial X}{\partial T}\right)_{P,n} \mathrm{d}T + \left(\frac{\partial X}{\partial P}\right)_{T,n} \mathrm{d}P \tag{15}$$

This equation contains the effect of temperature and pressure, reflecting that the partial molar quantity still is a function of temperature and pressure (Yang & Wu, 2003; Liu, 2005).

Obviously, when $\mathrm{d}T = 0$, $\mathrm{d}P = 0$,

$\sum_{i=1}^{m} n_i \mathrm{d}X_i = 0$ (Gibbs-Duhem equation, common form);

Also, $\sum_{i=1}^{m} n_i \sum_{j=1}^{m} \left(\frac{\partial X_i}{\partial n_j}\right)_{T,P,n\neq n_j} \mathrm{d}n_j = 0$ too, after comparing (11) with (12).

Therefore, the condition of $\mathrm{d}T = 0$ and $\mathrm{d}P = 0$ can be regarded as a special case of the change of temperature and pressure, regardless of this condition happens to be consistent with one of the conditions required when defining partial molar quantity.

Or Equation (13) is equal to $\sum_{i=1}^{m} n_i \mathrm{d}X_i = 0$, ($\mathrm{d}X_i = \sum_{j=1}^{m} \left(\frac{\partial X_i}{\partial n_j}\right)_{T,P,n\neq n_j} \mathrm{d}n_j$).

Induction of thinking: Why would the derivation cause such a result? This reason still comes from the establishment of a physical model-a very large homogeneous macro system, which makes it possible for the partial molar quantity to have the feature of a zero-degree homogeneous function.

In summary, no matter whether the temperature and pressure change, we can always obtain this equation. The acquisition of this equation is actually determined when the partial molar quantity is defined, because the physical meaning of the partial molar amount is a rate of change. When other factors remain unchanged, only the change of the absolute quantity will not change the value of partial molar amount. However, the change of relative quantity between components (compositions) is an absolute key to affect the partial molar quantity (X_i). One X_i increases, and another X_j will decreases, and the final change will be made according to this ratio ($\frac{\mathrm{d}X_i}{\mathrm{d}X_j} = -\frac{n_j}{n_i}$).

3.2. The Application of Logical Thinking

This essential characteristic of zero-degree homogeneous function of partial molar quantity determines the acquisition of G-D equation, and constant temperature and pressure is only one factor, which is not the reason for the acquisition of this equation. At the same time, the logical thinking method in the derivation process of G-D equation is induction-deduction-induction, and this way of thinking is helpful for students to practice their creative thinking and consciousness.

Firstly, induction: the set formula is obtained from the limiting conditions of constant temperature and pressure. This process is from special case (constant temperature and pressure) to general.

Then, deduction: the set formula ($X = \sum_{i=1}^{m} X_i n_i$) has a general characteristics, and any extension quantity (X) is a function of temperature, pressure, compositions, and the ratio of compositions. The exact differentiation of $\mathrm{d}X = \mathrm{d}f\left(T, P, n\right)$ is compared with the differentiation of the set formula $\mathrm{d}X = \mathrm{d}\left(\sum_{i=1}^{m} X_i n_i\right)$, including the further differentiation of the partial molar quantity, and the G-D equation is obtained, which is not only suitable for variable temperature and pressure conditions, but also for constant temperature and pressure conditions. This process is from general to special case (constant temperature and pressure).

Finally, induction: the construction of G-D equation is based on the essential and basic characteristics of partial molar quantity-zero-degree homogeneous function. This derivation process essentially emphasizes the common attributes of partial molar quantity and G-D equation: common great homogeneous macro-system.

However, at present, most textbooks in China do not consider the re-derivation of the partial molar quantity, ignoring the effect of temperature and pressure when deriving the G-D equation, which is inappropriate (Shao et al., 2017; Fu et al., 1990). Although the result of G-D equation is the same, the thinking mode is different.

As a comparison, the conventional derivation in textbook in China is as follows.

Due to the set formula: $X=\sum_{i=1}^{m} X_i n_i$.

$$\text{So, } dX^{(1)}=\sum_{i=1}^{m} X_i dn_i+\sum_{i=1}^{m} n_i dX_i \quad (16)$$

Due to the function $X=f(T,P,n_1,\cdots,n_m)$.

So, $dX^{(2)}=\sum_{i=1}^{m} X_i dn_i+\left(\frac{\partial X}{\partial T}\right)_{P,n} dT+\left(\frac{\partial X}{\partial P}\right)_{T,n} dP$.

When dT = 0, dP = 0, obtained

$$dX^{(2)}=\sum_{i=1}^{m} X_i dn_i \quad (17)$$

By comparing (16) and (17), $dX^{(1)}=dX^{(2)}$, then, $\sum_{i=1}^{m} n_i dX_i=0$.

Obviously, the above process is simple and inadequate because of $dX^{(1)}\neq dX^{(2)}$. The d$X^{(1)}$ is the exact differentiation of set formula, and as a thermodynamic function, this $X^{(1)}$ has general applicability and is affected by other thermodynamic properties. At the same time, it is also necessary to consider that partial molar quantity is also affected by these properties, such as temperature and pressure and composition. On the contrary, for $X^{(2)}$, its scope of application is reduced, because constant T and P is just a special case, which is not universalistic, moreover, the re-differentiation of the partial molar quantity is not considered too.

This mode of thinking cannot well reflect the context of logical thinking. We cannot only derive this equation from a special case, because it hides universal adaptability. Although this specific condition has always been valued by us (because it is a defined condition), this derivation does not inspire and guide students' thinking. Obviously, the establishment of the physical model and the assurance of the conditions are the key to learn this equation well. It also provides a good reference for students to study related majors.

For example, reasoning is an important form of logical thinking just like concepts and judgments. It is a thinking process of getting another judgment according to one or some judgments. Formally speaking, reasoning usually reflects the connection between judgment and judgment, which is often expressed by some statements embodying conditions or causality, such as "Only the state function with extensive property has partial molar quantity, so the state function with strength property does not have partial molar quantity" and "Because of the isothermal and heat-free exchange for ideal gas, there is no volume work in the process of vacuum expansion, for the whole system Q = 0, W = 0, so the change of thermodynamic energy ΔU = 0.

The following is a discussion of the significance of innovative thinking in the development of modern science and technology from the enlightening perspective of this thinking on innovation.

4. The Significance of Training Thinking

Dialectical materialism considers that thinking is an active reflection of objective things based on the knowledge of perceptual materials. Through thinking activities, people can gradually grasp the essence and changing law of things, further form a conceptual understanding of things, and thus make judgment and reasoning. Therefore, the training of thinking is of great significance to college students in future work, which can provide a convenience, rapid and effective method to find and solve problems. For example, for students majoring in geology, to deeply understand the evolution process of magmatic rocks and metamorphic rocks, it is an important means to use thermodynamic simulation, so it is necessary to understand the relevant thermodynamic concepts and grasp an effective thinking ability.

By the derivation of partial molar quantity and set formula, students can learn the basic form and skill of reasoning, form argumentative and logical thinking habits and communication skills, and form the ability to draw inferences from one example to another. Teachers should emphasize the derivation process of the formula, guide students to experience the formation process of the mathematical formula personally. Only in this way can the students really understand the mathematical formula thoroughly. The learning of new things needs a gradual process, and psychological research indicates that the learning effect of meaning memorization is significantly better than that of mechanical memorization when learning a knowledge point. Therefore, teachers and students finish the learning process together, resulting in the students' meaningful learning effect. Students can deepen their perception and understanding of the formulas they have learned, and produce really their internal incentive and get a sense of accomplishment. Compared with external incentive, internal incentive has the following two advantages. Firstly, internal incentive is more effective in maintaining students' long-term purposeful learning. External incentive can quickly stimulate students' learning behavior, but this kind of stimulation is often temporary. The learning behavior resulted from internal incentive is relatively slow, but this kind of stimulation is lasting and even lifelong. Secondly, external incentive generally needs to set some specific goals, thus guiding students' learning behavior. Once the students reach these set goals and get external incentives, such as some material rewards or praise, they are likely to stop studying or reduce the enthusiasm of studying. However, students with high internal incentive pay more attention to the learning activities themselves, and the achievement of the goals themselves will also become a stronger internal incentive. Instead of stopping learning, students may be encouraged to study further, so that students can spend more time and energy in learning activities, and thus they are more likely to achieve real achievements. For example, those great scientists and thinkers who can make truly outstanding contributions are high-intensity internal motivators. Finally, teachers should try their best to create a situation that is conducive to students' concentration and motivation to learn, and make students produce stronger internal incentive for studying.

In addition, students get the training of thinking ability through internal incentive studying and promote the development of innovative thinking ability, and innovative thinking refers to the thinking process of solving problems with unique and novel methods. It is a high-level form of human thinking, a high-level expression of intelligence, and a crystallization of a variety of thinking with novelty and uniqueness. With divergent thinking as the core, divergent thinking has the characteristics of fluency (referring to thinking a lot of problems in a short period of time, very fast), flexibility (variability, the problems that come to mind, belonging to multiple different scopes) and originality (uniqueness, found by oneself alone, very novel). The acquisition and formation of creative thinking ability is not overnight, which requires college students to hard work and active participate in various study and entrepreneurial activities.

Firstly, these students study some theoretical knowledge about innovative thinking, including the basic concepts of creative thinking, the basic principles of creative thinking, and the methodology of creative thinking, moreover, it is more important to actively practice them. Of course, the study of curriculum theory is also very important, not only providing excellent thinking training cases, but also laying a solid professional foundation for future work, as discussed above. Next, students should dare to think independently and tap their own internal potential. Finally, schools should accelerate the transformation of education concepts and deepen education reform, at the same time, schools and society should provide more practical and feasible innovation and entrepreneurship platforms for college students.

The research on innovation and entrepreneurship has a long history. However, the comparative and systematic research began in the 1930s with Schumpeter's research on innovation theory and Osborne's research on creativity (Malerba & McKelvey 2020; Penuel & Furtak 2019). The first rise appeared in the late 1960s, the most famous being entrepreneurship education in American universities. At present, entrepreneurship education in the United States has been incorporated into the national education system. Many famous American high-tech companies in the contemporary era are almost all created by college entrepreneurs using venture capital, such as Intel's Moore, Grove, Microsoft's Bill Gates, HP's Hewlett and Packard, Netscape's Andreessen, etc. Innovation ability includes creative thinking ability, creative practice ability, and the other non-intellectual factors. Of course, creative thinking ability is decisive and the most important because all innovation comes from the innovation of thinking. Therefore, the training of innovative thinking ability is very important for college students.

With the development of modern enterprises, there are more and more high-tech enterprises and less and less demand for ordinary workers. Therefore, in their daily study, college students continuously improve their innovative thinking. Only by enhancing their innovative ability, changing employment concepts and actively participating in innovation and entrepreneurship can they develop themselves. In addition, the development of the country and society cannot be separated from the support of talents, and even from the support of innovative talents.

Therefore, only by improving their own innovation awareness and innovation ability can college students contribute to the development of society, technology, and economy.

Taking the student work of Tao's research group as an example (Jin et al., 2020a, 2021), it is briefly introduced the training and gain of students' innovative thinking in scientific research work as below. At present, the rapid growth of population, urbanization and industrialization has recently caused more and more severe environmental problems including water pollution. The graphene-based new materials are attracting more and more attention in the scientific community due to their unique properties. The surface of graphene oxide (GO) is rich in active groups such as epoxy groups, carboxyl groups, and hydroxyl groups. GO has a large specific surface area and good dispersibility in water and excellent reactive activity and becomes a preferred material with high capacity and high selectivity. Therefore, in our research group, some students have prepared some new GO monolith for coatings, such as, the application of graphene-based adsorption materials has been expanded to the anticorrosive coating industry by some students (Jin et al., 2020b, 2022, 2023), showing their innovation and pioneering consciousness, indicating the positive role of innovative thinking in the technology research work.

5. Conclusion

Education is a way of inheriting culture, whose ultimate goal is to make people beneficial to the society. Teaching is the basic way to carry out this goal. The most effective form of disseminating systematic knowledge is school education and teaching, and self-perception theory indicates that internal incentive is more effective in maintaining students' long-term purposeful learning than external incentives. Teachers guide students to get internal incentive by an example of teaching, which not only strengthens the training of scientific thinking, but also provides a greater sense of achievement using a new method to solidify students' motivation to learn.

Taking the new establishment process of the G-D equation as a teaching example, a heuristic teaching method is used to guide students' thinking, and a distinct logical thinking process is emphasized in the derivation process: induction-deduction-induction, and this way of thinking is helpful for students to practice their creative thinking and consciousness. The new derivation process not only highlights the dialectical nature of thinking, but also clarifies the source of the problem: a physical model composed of a very large homogeneous macro system and a zero-degree homogeneous function of partial molar quantity is the main essential reason and characteristic of reasonable derivation.

The study of theoretical courses is beneficial for the training of logical thinking and the acquisition of internal incentive, which is also helpful for the scientific research and the development of society, economy and science and technology, taking the students' work of our research group as an example.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Atkins, P., & De Paula, J. (2014). *Physical Chemistry* (10th ed.). Oxford University Press.

Bender, J. (2020). Dōgen's "Leaving Home Life" (*Shukke*): A Study of Aesthetic Experience and Growth in John Dewey and Dōgen. *Philosophy East and West, 70,* 42-62. https://doi.org/10.1353/pew.2020.0014

Erbil, D. G., & Kocabaş, A. (2020). Flipping the 4th Grade Social Studies Course in a Cooperative Way: Effects on Academic Achievement and Motivation. *Studies in Educational Evaluation, 66,* Article ID: 100878. https://doi.org/10.1016/j.stueduc.2020.100878

Fu, X., Shen, W., & Yao, T., (1990). *Physical Chemistry* (4th ed.). Higher Education Press. (In Chinese)

Jin, T., Huang, C., & Zhang, F. (2023). Corrosion Resistance of N-(Hydroxymethyl)acrylamide Cross-Linked Nano-Graphene Oxide/Epoxy Resin Composite Coating on Magnesium Alloy. *Journal of Metals, 75,* 656-668. https://doi.org/10.1007/s11837-022-05569-6

Jin, T., Kong, F., Wu, Z., & Zhao, X. (2020a). Phenomenology of the Entropy of Mixing of Polymer Solutions. *Journal of Materials Education, 42,* 119-130.

Jin, T., Kong, F., Yan, B., Zhang, G., Liu, Q., He, Q., & Zhou, X. (2022). Teaching and Learning Dialectical Relationship between Thermodynamic Equilibrium and Reaction Rate Constant. *Educational Sciences: Theory & Practice, 22,* 29-41.

Jin, T., Kong, F.-M., & Zhao, P.-W. (2021). Graphene Oxide Aerogel Assembled by Dimethylaminopropylamine/Nisopropylethylenediamine for the Removal of Copper Ions. *Chemosphere, 263,* Article ID: 128273. https://doi.org/10.1016/j.chemosphere.2020.128273

Jin, T., Zhang, Q., Yin, H., Cole, I. S., Zhao, P., Wang, Y., & Liu. X. (2020b). Corrosion Resistance Mechanism of Itaconic Acid Doped Polyaniline/Nanographene Oxide Composite Coating. *Nanotechnology, 31,* 285704-285716. https://doi.org/10.1088/1361-6528/ab824a

Liu, Y. (2005). On Partial Molar Quantity Collective Formula and Deduction of Gibbs- Duhem Equation. *Journal of Weinan Normal University, 20,* 3-4, 18. (In Chinese)

Malerba, F., & McKelvey, M. (2020). Knowledge-Intensive Innovative Entrepreneurship Integrating Schumpeter, Evolutionary Economics, and Innovation Systems. *Small Business Economics: An Entrepreneurship Journal, 54,* 503-522. https://doi.org/10.1007/s11187-018-0060-2

Penuel, W. R., & Furtak, E. M. (2019). Science-as-Practice and the Status of Knowledge: A Response to Osborne. *Science Education, 103,* 1301-1305. https://doi.org/10.1002/sce.21541

Shao, Q., Chen, W., & Yang, J. (2017). *Physical Chemistry* (2th ed.). Chemical Industry Press. (In Chinese)

Tasdemir, C., & Gazo, R. (2020). Integrating Sustainability into Higher Education Curriculum through a Transdisciplinary Perspective. *Journal of Cleaner Production, 265,* Article ID: 121759. https://doi.org/10.1016/j.jclepro.2020.121759

Taylor, B. (2020). Philosophical Solitude: David Hume versus Jean-Jacques Rousseau. *History Workshop Journal, 89,* 1-21. https://doi.org/10.1093/hwj/dbz048

Wagenschein, M. (2010). Experimentelle Untersuchung über das Mitschwingen einer Kugel in einer schwingenden Flüssigkeits- Oder Gasmasse. *Annalen der Physik, 370,* 461-480. https://doi.org/10.1002/andp.19213701305

Yang, Y., & Wu, F. (2003). On the Derivation of Gibbs-Duheim Equation. *University Chemistry, 18,* 26-27, 30. (In Chinese)