Designing White Space for Chemistry Education With the Inspiration of Chinese Artistry

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Abstract

White space is an artistry concept widely used in Chinese painting and calligraphy. It conveys useful information for the readers while retaining certain imagination space for them. Inspired by this artistry, we probe into the white space designing in chemistry education and scientific training in colleges/universities. A few examples are illustrated for the utilization of white spaces in scientific knowledge teaching with detailed discussions. These include half-life time of dynamic studies, mathematical derivation of chemical calculations, equilibrium of chemical reactions and phases of thermodynamics, as well as data processing in scientific studies & developments. Designing white space in lectures/presentations aims to rhythmize the teaching process and to prevent fatigue from both the lecturer and students by cutting off lengthy talking. Moreover, leaving suitable white space in the teaching content may arouse the curiosity of students, stimulate the desire for their exploration, and therefore enrich their learning experiences. We herein propose the designing of appropriate white space in college chemistry education with pernitent examples to promote further discussions on this issue.

Keywords: white space design in education, chemistry, scientific training, Chinese painting, college courses

1. Introduction

1.1 Influences of Information Technology on Education

The formation of unique lifestyles in different eras of human history is closely related to the development of science and technology. At the present, search engines and the internet provide an extremely fast and convenient platform for spreading information and providing solutions to various questions or problems. Therefore, conventional teaching in class based on one’s understanding and experiences could hardly meet this information-boosting era. In this respect, it is highly challenging to pass on the experiences or knowledge to the students using an adaptable teaching methodology. Briefly, it is important for the teachers to perform educational work effectively by adopting appropriate methods according to the characteristics of the individual students.

In recent years, various new teaching and training techniques or models emerged as a result of the rapid development of information technology. At this point, online courses including Massive Open Online Courses (MOOC) have been developed worldwide. Various teaching models such as the Flipped Class Model and Problem-based Learning (PBL) have been rapidly developed and put into practice. Traditional in-person or offline lectures are also gradually replaced by online virtual classes or the integration of both online and in-person models. In other words, classroom curriculums are no longer the only way for students to acquire knowledge, they have more access and options to different courses or teachers. In addition, the typical big-class teaching mode in China which usually holds a capacity of about one hundred students has been gradually replaced by the intelligent classroom to enable more active interactions between the teachers and the students. Even experimental training, an essential and most important part of chemical education has introduced online virtual laboratory and the conventional experiments act as an additional educational resource for practical operation. Especially, virtual classrooms and online teaching have both played important roles in filling the vacancy of "face-to-face" teaching during the pandemic of COVID-19 since 2020.

1.2 Problems to Consider for a Teacher

Generally, a course will remain to be designed and demonstrated by teachers regardless of changes in teaching facilities, models and environmental situations. Thus, the educational concepts and thoughts of the teachers will determine the teaching performance and the outcome. Moreover, the meaning of education not only refers to the end of term Grade-Point Average results, but also rests with the influence retained in the future. The effective education is, therefore, evaluated as what quality is acquired by the students when the memorized concepts and formulas have been forgotten with time. From this point of view, the teachers should be able to stimulate the interests of the students and to dig their vast potentials in learning and creation. As the saying goes “intelligent teachers give the students fishing skills instead of handing them fishes”.

1.3 White Space Design in Education

We propose an idea of "white space design in education" and use it as a practical example in chemistry teaching by considering the wide influence of the internet and social media. The white space is a kind of artistic expression, which have been widely used in Chinese art including painting and calligraphy, especially in ancient Chinese landscape painting. It is a simple but unique way to not only give the readers a general impression of the art piece, but also leave appropriate room for the individual imagination. In the education process, direct experiential knowledge transfer by cramming has never been advocated. Instead, leaving students with white space is showing respect to their own ideas and development choices based on their individual specialty and personality, *i.e.*, having time and space to observe, think, understand, and reflect, as well as to develop and create in their own ways.

1.4 Why Designing White Space in Education?

In general, the white space in artistic works is deliberately designed by the creators. Appropriate white space is an indispensable component to achieve an exquisite and harmonious balance between the whole picture and the elements, which could lead the readers to their own imagination. As a result, the white space is designed by the creator, but enriched in various readers' minds with abundant creation. This artistry is a perfect illustration of the Chinese philosophy "less is more". The average percentage of white space or empty space in the landscape painting from the Yuan dynasty is found to be as high as 61.7%. Inspired by this artistic technique, we propose the concept of "white space design in education" and probe into this idea in chemistry teaching and scientific training in universities with the aim of achieving more by the students. Designing white space in teaching is supposed to benefit individual self-development and lifetime long-learning as well as to respect the individual capability and personality.

2. Method

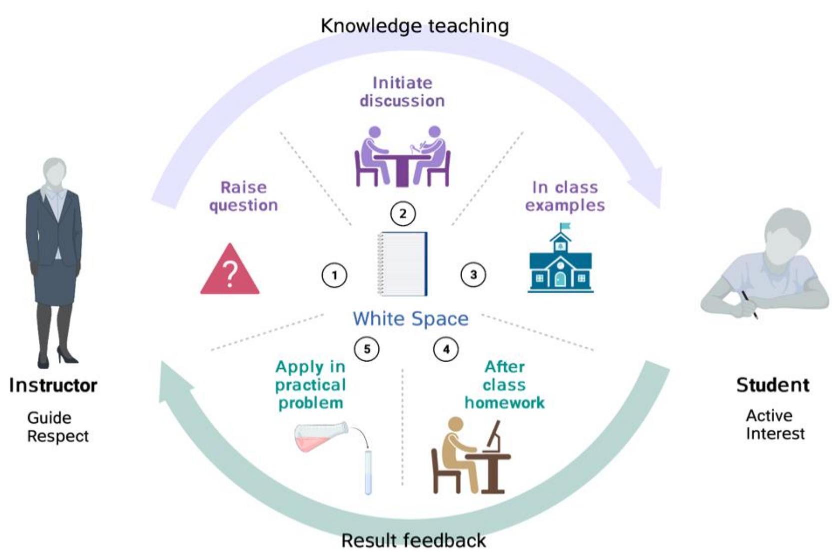

Figure 1. Schematic illustration of the possible white space design in the lectures (created with BioRender.com)

Interest is known to be the best teacher and acts as an effective driving force for learning. Therefore, the teachers tend to guide the students to actively engage in the learning process *via* questioning, discussing, Flipped Class Model, as well as afterclass homework. Designing white space in lectures refers to leaving suitable empty space in the teaching content for the students to imagine, think, and explore. As illustrated in Figure 1, based on one point of knowledge, there are many possible aspects to include white spaces that could extend the course to afterclass learning activities. In addition, the students get to decide what specific topics they want to focus on and study. Information technology provides students with more convenience to acquire their knowledge of interests. In comparison with the "one-way output" teaching method from the instructors, the active participation from the students which results from the white space incorporation in education could inspire more imaginative and creative thinking.

Similarly, the instructors need to incorporate white space in lectures to help the students actively engage in learning. For the purpose of attracting people to recognize, accept or use educational white space in their teaching activities, we herein give some examples of white space to serve as a sprat for further attention and discussions.

2.1 Design White Space in Lectures

The class teaching is unable to cover every aspect of the course content due to the limitation of time. An experienced teacher would avoid giving lectures by only listing out the facts and results, he/she may introduce a new concept or knowledge by first raising a question and initiating a discussion. The students are more likely to be attentive, active, and thoughtful during the discussion than that during the lectures of talking. In reality, the students have to deal with many problems and make exploration by themselves in their future work. Therefore, when introducing a scientific law, a few examples and a white space of problems should be given to the students, with the aim of benefiting them from active participation and making the lectures more enjoyable. At the end of the lecture, homework, as a part of the vital professional training in colleges, is normally assigned to the students. From the feedback of the students the teachers could examine whether the designed white space in the class is suitable for the majority of the students.

2.2 Design White Space in Scientific Training

To senior or graduate students, scientific training is highly important to be competent in their future careers. Thus the focal point is to teach or guide the students to acquire the necessary capabilities for solving complex problems through scientific training. In this respect, designing white space from the fundamentals of chemistry principles might provide a suitable choice.

By looking back at the history of the development of science, one can find that scientific principles and concepts have been continuously amended or corrected from time to time due to the limitation of human cognitive capability. The development of perfect gas to actual gas, ideal solution to dilute solution, and the ionization of acids and bases in aqueous solution to Lewis acid-base theory, illustrate great examples to corroborate that amendments and corrections are frequently involved in the development of sciences and serve as important driving forces for the advancement of sciences. It takes a relatively long time to illustrate the knowledge gap, complexity and contradictions, and the demonstration of their connections along with debates may promote the development of sciences. Professor Weinberg gave one of his four golden lessons: "while you are swimming and not sinking, you should aim for rough water. ..." His advice to the students is to go for the challenges - that's where the action is.

The concept of catalyst gives another example to illustrate the process of human cognition and the necessity of leaving blank for scientific development. Professor W. Ostwald proposed the concept of catalyst as "any substance that alters the velocity of a chemical reaction without modification of the energy factors of the reaction" in 1895. In 1902, he corrected the concept twice. The first correction is "a catalyst is any substance that alters the velocity of a chemical reaction without appearing in the end product of the reaction". The second reversion is "a catalyst is any substance that alters the velocity of a chemical reaction without itself being changed by the process". In 1996, the International Union of Pure and Applied Chemistry established the novel concept of catalyst as "a catalyst is a substance that increases the rate of reaction without modifying the overall standard Gibbs energy change in the reaction".

3. Results

3.1 White Space in Lectures

3.1.1 Half-Life Time of the Reactant

Half-life time is an important concept to evaluate how much a reactant has been consumed *via* a specific chemical reaction. For the quantitative determination of the half lifetime of a reactant, only several equations are introduced as shown in Table 1, wherein there is only one kind of reactant species A. As referred to the other cases and complex reactions, the white space is left instead of equations. The students are thus asked to discuss how to deal with the half-life time issues in different situations. Such as the supply of two reacting species of A and B equivalently and inconsistently.

Table 1. Integrated rate laws

Order	Reaction	Rate (v) law*	Half-life time ($t_{1/2}$)	Mathematical equation
0	$A \to P$	$v = k$ $kt = x$ for $0 \le x \le [A]_0$	$\frac{[A]_0}{2k}$	$\int_0^t k dt = kt$
1	$A \to P$	$v = k[A]$ $kt = \ln\frac{[A]_0}{[A]_0 - x}$	$\frac{\ln 2}{k}$	$\int_{[A]_0}^{x} \frac{dx}{[A]_0 - x} = -\ln\frac{[A]_0 - x}{[A]_0}$
2	$2A \to P$	$v = k[A]^2$ $kt = \frac{x}{[A]_0([A]_0 - x)}$	$\frac{1}{k[A]_0}$	$\int_0^x \frac{dx}{([A]_0 - x)^2} = \frac{x}{[A]_0([A]_0 - x)}$
	$A + B \to P$	$v = k[A][B]$ $kt = \frac{1}{[B]_0 - [A]_0}\ln\frac{[A]_0([B]_0 - x)}{[B]_0([A]_0 - x)}$	**?**	$\int_0^x \frac{dx}{([A]_0 - x)([B]_0 - x)} = \frac{1}{[B]_0 - [A]_0}\ln\frac{[A]_0([B]_0 - x)}{[B]_0([A]_0 - x)}$
3	$3A \to P$	$v = k[A]^3$ $kt = \frac{1}{2}\left\{\frac{1}{([A]_0 - x)^2} - \frac{1}{[A]_0^2}\right\}$	$\frac{3}{2k[A]_0^2}$	$\int_0^x \frac{dx}{([A]_0 - x)^3} = \frac{1}{2}\left\{\frac{1}{([A]_0 - x)^2} - \frac{1}{[A]_0^2}\right\}$
	$A + 2B \to P$	$v = k[A][B]^2$ $kt = \frac{2x}{(2[A]_0 - [B]_0)([B]_0 - 2x)[B]_0} + \frac{1}{(2[A]_0 - [B]_0)^2}\ln\frac{[A]_0([B]_0 - 2x)}{[B]_0([A]_0 - x)}$	**?**	$\int_0^x \frac{dx}{([A]_0 - x)([B]_0 - 2x)^2} = \frac{2x}{(2[A]_0 - [B]_0)([B]_0 - 2x)[B]_0} + \frac{1}{(2[A]_0 - [B]_0)^2}\ln\frac{[A]_0([B]_0 - 2x)}{[B]_0([A]_0 - x)}$
$n \ge 2$	$A \to P$	$v = k[A]^n$ $kt = \frac{1}{n-1}\left\{\frac{1}{([A]_0 - x)^{n-1}} - \frac{1}{[A]_0^{n-1}}\right\}$	$\frac{2^{n-1} - 1}{(n-1)k[A]_0^{n-1}}$	$\int_0^x \frac{dx}{([A]_0 - x)^n} = \frac{1}{n-1}\left\{\frac{1}{([A]_0 - x)^{n-1}} - \frac{1}{[A]_0^{n-1}}\right\}$

* $v = dx/dt$; k is the reaction rate constant; $[A]_0$ and $[B]_0$ are the initial concentrations of the reactants A and B.

3.1.2 Mathematical Derivation

Mathematical formulation is commonly used in chemical principles, especially in Physical Chemistry and Structural Chemistry. In some cases, mathematical derivation is essential and even required for the students to better understand the experimental results and the theoretical aspects behind them. However, too many derivations may dilute the major contents of chemistry itself. Therefore, leaving appropriate white space of mathematical derivation for the students is required to focus on chemistry principles and knowledge. For instance, the collision density is an important factor in governing the reaction rate according to the collision theory. The formula of collision density is induced from a system containing two species of A and B. In a particular situation, when the system contains only a single species A, the mathematical derivation is absent in all the textbooks as shown in Figure 2. The mathematical derivation given in the box of lower right corner could be assigned as a discussion topic for the students.

There are a large number of formulas in both thermodynamics and kinetics in Physical Chemistry. This makes it quite challenging for the students to memorize, thus often gives some students the impression that Physical Chemistry is hard to learn. In fact, most of the formulas can be derived from the chemical equations or the original formula based on the principles such as the law of mass conservation. In chemistry, this law may be presented as the material balance equation and the charge balance equation, *i.e.*, the electro-neutrality principle. The most used mathematical equations are fundamental formulas of calculus as seen in Table 1 with the equations for relative derivations given in the last column. These are normally provided as an appendix in the textbook to help the students to derive equations by themselves whenever necessary.

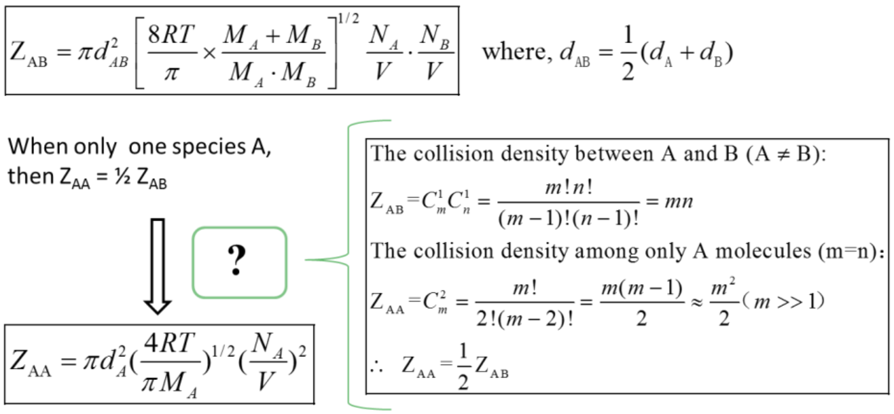

Figure 2. The formula of collision density and the related mathematical derivation

Similarly, there are many equations for the calculation of pH values in Analytical Chemistry. Very recently, Shao provided a formula-free system for this course with the assistance of pervasive computing. More details have been published elsewhere and will not be described herein.

3.1.3 Equilibrium of Chemical Reactions and Phases

The reaction and phase equilibriums are important contents which generally given in separate chapters in Physical Chemistry. To deal with the relative processes, a parameter of changes in molar Gibbs free energy (ΔG_m) or chemical potential (μ_B) is commonly used. In the chemical reaction equilibrium, the system under consideration is generally defined in a closed aqueous solution. To expand it into complex heterogeneous systems, white spaces could be designed in the teaching. If simply inducing the hypothesis and conclusions from homogeneous solutions into a broad field such as reactions among solid phases, queries would be raised. One of the questions may be that "will the chemical reactions definitely reach the equilibrium"? Another question may be "does the chemical potential μ_B of the reactant (B) equal to that of its produced species"? The answers are negative. For the first question, the chemical reactions involving different phases should follow the phase law at fixed conditions. The solution to the second one is that the chemical potential μ_B is an intensive property, which is not as additive as that in the case of extensive parameters. Therefore, the comparison of the value for chemical potentials between the reactant and the product is invalid.

3.2 White Space for Scientific Training

The students in chemistry majors need to take scientific training in order to be qualified for their future professional careers. To solve practical problems, one has to be capable of dealing with more complicated problems by considering many relative factors. For instance, for obtaining a high yield of a product *via* a specific chemical reaction, one of the most important concerns is the control of temperature, *e.g.*, choosing the appropriate temperature for the reaction in practice. From thermodynamics, a lower temperature is beneficial to achieve more products since the chemical equilibrium would shift towards the product. On the other hand, however, a lower temperature is of detriment to reach a high reaction rate according to the dynamics, which in turn decreases the yield of the product. Moreover, the costs on the management of processes and experimental conditions, as well as the issue of displacing the reaction equilibrium should be comprehensively considered practically, these types of white space may be left to the students in their future careers.

To endow the students with the ability to deal with professional work, scientific training with designed white space are required. The following examples are given for illustrating this kind of training.

3.2.1 Statistics and Data Analysis

Analyses of data and the reporting of the results of those analyses are fundamental aspects for conducting research. Accurate, unbiased, complete, and insightful reports of the analytical treatment of data, regardless of quantitative or qualitative, is inevitable in all scientific activities. The researchers in the field of psychology use numerous approaches to the analysis of experimental data, and no one approach is uniformly preferred as long as the method is appropriate to the research questions and the nature of the data collected. The methods used must support their analytical burdens, including robustness to violations of the assumptions that underlie them, and they must provide clear, unequivocal insights into the data.

3.2.2 Standard Graphs

Standard curves are usually used in Analytical Chemistry for quantitative analysis of a specific target in the samples. In practical works, the linear calibration graph is frequently obtained within a certain concentration range of the reference material as schematically shown in Figure 3a. The students may often raise such a question as is it reasonable to extend the linear graph beyond the standard concentration range (Figure 3b)? The answer is definitely no because the linear relationship may no longer exist at a concentration out of the investigated range. However, with regard to more cases, leaving the answer as a white space would be advisable and reasonable.

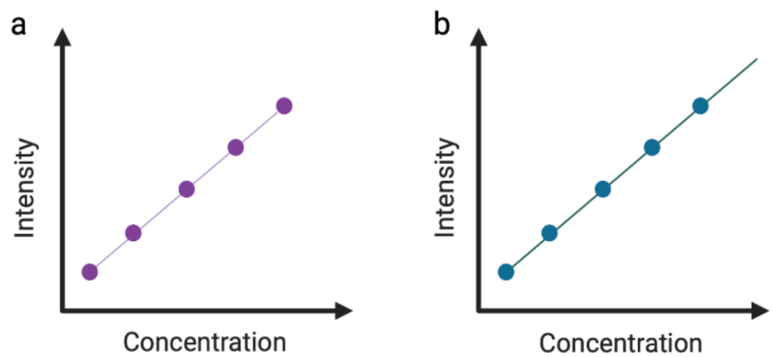

Figure 3. Schematic illustration of the linear calibration graphs between concentration of the target and the intensity (created with BioRender.com)

Two papers published recently debated on whether the logarithmic data processing can be used justifiably in the establishment of a calibration graph. One of the reports provided justification and legitimacy for the application of logarithmic processing in various fields of quantitative Analytical Chemistry. They declared that a fitted function with a good coefficient of determination within a wide concentration range permits the expansion of the detection range as much as possible on the basis of ensuring detection sensitivity. This has significant implications to rationalize the choice of a particular analytical method. However, a later report indicated that for the use of a limited number of experimental data to predict the full-scale unknown data points, a reliable fitting should follow the signal transformation mechanism rather than merely the statistical data.

From a scientific point of view, it is quite risky to optionally expend the functional relationship as that acquired under fixed conditions is restrictive. The existing correlation may very likely change when extending to a wider range. For example, intercepting a part of a sinusoidal curve might fit to a linear relationship, while this relationship is obviously not the overall characteristic of the sinusoidal curve. From the perspective of the development of science and technology, it is needed to leave white space for the indefinitely known zones.

3.2.3 Limit of Detection (LOD)

The limit of detection is a basic concept in Analytical Chemistry, which is used as a parameter to evaluate the sensitivity of an analytical protocol. It may be expressed as three times the blank standard deviation (σ) or three times the signal-to-noise ratio, the slope of the linear standard graph, and the ratio of 3σ to the slope of the standard graph. For the analytical approaches without blank samples, however, the generally used procedure for the determination of the limit of detection is not applicable. This might be a good example of white space for discussion in the lecture on Analytical Chemistry. For instance, in the case of the ratiometric fluorescence or spectrophotometric analytical processes, the commonly adopted slope of the linear calibration graph would be incomparable and meaningless. This is due to the fact that the slope is not only related to the sensitivity of the method, but is also affected by the relative difference of the fluorescence intensity at two emission wavelengths. These two parameters may be increased or decreased at the same time, or changed in an opposite direction corresponding to different fluorescence or absorption properties of the samples. In these cases, the universal limit of detection is nonexistent and the existing definition is incomparable. The white space herein for measuring the sensitivity of ratiometric fluorescence protocol provides an opportunity to solve the problem and explore the solutions in scientific training for the students. We have discussed various situations in ratiometric fluorescence measurement to clarify the pros and cons of adopting the slope of the standard calibration graph as the sole parameter in scientific training for students.

3.3 White Space Designing Beyond Lectures --- Advices and Suggestions to the Students

Professors are sometimes invited to give advice and suggestions, or answer queries from the students involving major or supervisor selections, career experience, *etc*. In this situation, telling a familiar allegory but leaving white space for its meaning might be a good way, *i.e.*, moral white space model.

In China, the allegory of "a pony crosses the river" is a very popular fable. Briefly, a pony was heading for the mill, but a river got into his way. He hesitated as he didn't know the depth of the river. He asked the ox if he could cross the river safely. The ox told him the river water only reached his lower leg (calves). As the pony decided to cross the river, a squirrel jumped out and stopped him, saying his friend fell into this river yesterday and drowned. The pony was very confused and he went back home to ask his mom for advice. His mom encouraged him to try by himself. Thus the pony stepped into the river and gained his own experience for the first time. The river is neither as shallow as the ox told him nor as deep as the squirrel said.

The students, sometimes, get the impression from their mentors or senior students that Physical Chemistry is difficult to understand in comparison to the other chemical courses, *e.*g., Inorganic/Organic Chemistry and Analytical Chemistry. We usually encourage beginners to "cross their own rivers" like the pony. Similarly, the educational white space can be found in many pieces of literature such as fables written by Ivan Andreyevich Krylov. Since people have different backgrounds, take diverse routes in life, and gaining all kinds of experiences, therefore they do not share the exact same empathy. Designing white space in education is more instructive to a broad audience. We propose the concept and give teaching examples of white space designing in order to attract further invaluable discussions and exploitations.

4. Discussion

Learning capacity is an indispensable quality for people to keep up pace with the rapid development of modernization. This makes learning a lifelong and endless process. For the purpose of passing on skills of social adaptation, the capability of learning should be stressed in modern education. Therefore, it is of high significance for educators to improve their teaching ability and to explore teaching art. We proposed the idea of carrying out "white space design in education" in order to make it more restrained and connotative, as well as broaden the students' imagination and development space. Gustave Flauber pointed out that "the more time goes by, the more art will become scientific and conversely, the more science will become artistic. Both will unite at a summit after having been separated at the base." With the artistry of white space design as the reference in teaching endows modern education with goals to respect the special needs and individuality of the students. As a teacher faces a group of students, the choice of designing white space may effectively enlighten their minds with blooming ideas, since the same scene may activate different imaginations of different people. Just like the saying goes there are a thousand Hamlets in a thousand people's minds. For future practices in education, the following perspectives may give guidance to the design of white space.

- Designing educational white space is more instructive to a broad crowd. The key point of white space design is to stimulate and cultivate students' interests since active participation is far more rewarding than passive acceptance.
- One of the most important issues for designing white space in lectures should be focused on the development of knowledge for the students. This may benefit them to explore and lead edge by crossing domains *via* "search engines".
- The present cognitive limitations of human beings require the white space in lectures to follow the rules of scientific findings and developments for making the students gain and understand knowledge as much as

possible and to create their future fulfillment in the learning process.

It is worthwhile to mention that white space designing is an educational skill or teaching art. However, there is still a long way to go before it is widely recognized regardless of minors or adults as the educational recipients. In addition, the teachers playing with this teaching skill need to better understand the philosophic idea, *i.e.*, “less is more”. It is extremely important to keep a “less-and-more” balance in creating educational white space. Furthermore, it is highly challenging to develop widely applicable white space in teaching as a specific white space might receive quite diffident results for different individuals. This may be a restrictive factor in the popularization of white space design.

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