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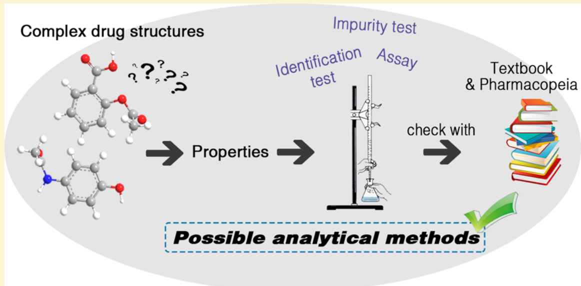
Applying a Chemical Structure Teaching Method in the Pharmaceutical Analysis Curriculum to Improve Student Engagement and Learning

Hui Zheng,*,[†] Binjing Hu,[†] Qiang Sun,[‡] Jun Cao,[†] and Fangmin Liu[†]

[†]College of Material, Chemistry and Chemical Engineering, Hangzhou Normal University, Hangzhou 311121, China

[‡]ARC Centre of Excellence for Nanoscale BioPhotonics (CNBP), School of Science, RMIT University, Melbourne, Victoria 3001, Australia

ABSTRACT: Pharmaceutical analysis, as the core curriculum of chemistry, chemical engineering, and pharmaceutical engineering, contains broad and in-depth knowledge that leads to massive learning and teaching loads. There are more than 100 analytical methods of medicines in this course. As such, this subject is a big challenge for both students and lecturers. A novel chemical structure teaching (CST) method was developed on the basis of our long-term teaching experience to cope with these challenges. It has been shown in practice that this CST method can significantly unload the stress of students and lecturers simultaneously. The survey about the improvement of students' interests was carried out and listed in the form of questionnaire. The outcome of CST indicates that it can help students to form abilities of critical and logical thinking, motivate them to discuss with their peers and lecturers, and eventually improve comprehensive abilities such as synthesizing information, thinking logically, and analyzing problems independently as well as the average score. Furthermore, CST can be beneficial for lecturers who teach other relevant curricula in chemical or pharmaceutical engineering to improve the teaching outcome, such as organic chemistry, spectrum analysis, pharmaceutical synthesis, and medicinal chemistry. This CST model can also help students cultivate a life-long learning ability as active learners from the cognitive perspective view.



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The development of skills such as problem-solving, critical-thinking, and life-long active learning by undergraduate students is very important for their future careers and lives.[1] Nevertheless, the inefficient capability cultivated by a traditional teacher-oriented style is still dominant in most universities,[2] in which students are merely required to receive the information from lecturers and then try to memorize it in a mechanical way. As such, the attitudes and self-concepts of students were pushed aside to a secondary place, which can normally lead to a lack of motivation and engagement in learning.[3] In particular, for students whose major is chemistry, chemical engineering, or pharmacy, many courses contain diverse, complex, and in-depth knowledge such as organic chemistry and medicinal chemistry. It is more difficult to lecture and learn effectively via that traditional lecturing procedure. Given the deficiencies and shortcomings of the conventional teaching process, novel and explicit teaching methods need to be developed to enable students to engage and be active learners, and eventually to develop as proficient and independent problem-solvers.[4]

In 1987, Chickering and Gamson[5] published a seminal paper that identifies seven universal practices in undergraduate education:

1. Encouraging student−faculty contact
2. Encouraging cooperation among students
3. Encouraging active learning
4. Giving prompt feedback
5. Emphasizing time on task
6. Communicating high expectations
7. Respecting diverse talents and ways of learning

From then on, many novel education methods have been implemented in chemical and pharmacy related courses based on these seven principles; for example, incorporating drug discovery stories in a pharmaceutical chemistry class[6] can greatly boost student−faculty interactions. Romero et al.[7] have applied a problem-based learning (PBL) method in a pharmaceutics course to assess its effectiveness in comparison with a didactic approach. Results showed that students who took the PBL lecture scored significantly higher than those in the didactic lecture. Green et al.[8] developed the covalent bond classification (CBC) method to help students understand relationships between molecules more comprehensively, which improves their ability to conceptualize and master the chemical properties of the elements.

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Pharmaceutical analysis, one of the core courses in pharmacy related majors and one of the required subjects for the licensed pharmacist examination, is a discipline that is necessary to meet the demand of overall quality control in drug R&D and manufacturing. It covers chemical and instrumental analysis methods ranging from synthetic medicine to natural medicine, biological medicine, and their agents.[9] For students to master this course, both being rich in knowledge of chemistry and pharmacy and having good experimental skills are indispensable. So, pharmaceutical analysis is usually set in the junior year to meet the requirement of combining cross-disciplinary knowledge and skills that students have learned in previous semesters that build a solid foundation for their future employment or research work, such as medicine quality control and analysis.

The pharmaceutical analysis course usually includes pandect (4 chapters) and subpandect (12 chapters).[10] The former covers the overview of fundamental analysis principles, methods, and common technologies, underlining the similarities and characteristics among drug analytical approaches. In general, pandect comprises the drug standard, identification test, impurity test, assay, biopharmaceutical analysis, and validation of analytical methods.[10] As for the subpandect, it includes the knowledge of identification, impurity limit test, and assay with more than 100 typical medicines, such as aromatic acids, nonsteroid anti-inflammatory drugs, *p*-aminobenzoate acid ester, etc. There are up to 12 categories in total. In addition, the analytical methods of bulk drugs and preparations from the Chinese pharmacopoeia (abbreviated as ChP 2015 edition, the same below)[11] are also covered in this course. All of these diverse, complicated, and in-depth contents definitely present a barrier to students' productive learning.

From our practical teaching experience, we found that students tend to lose initiative, become aimless, and feel anxious when facing so many complex chemical structures and analytical methods. Nevertheless, we noticed that it was always much easier and more interesting for them to learn pandect than the subsequent subpandect chapters. The problem might be the lack of clear and uniform logic to instruct the whole teaching and learning process. As a result, there is no surprise that students were more able to engage with pandect materials, which have a clear logic and are mainly based on what students have learned previously, relative to how they feel when learning subpandect.

Given the teaching and learning dilemma in pharmaceutical analysis, we firmly believed that a new education method was needed to enhance students' learning interests and efficiency. Herein, to deal with the above problem arising from the teaching and studying process, we developed a unique education method named "chemical structure teaching (CST)" after continuous exploration for many years. As suggested by the name, CST mainly focuses on the chemical structures of different drugs. With this method, students would easily and actively learn how to deduce possible properties and analytic methods according to specific functional groups, namely, to link what they've learned before in organic chemistry and analytical chemistry with pharmaceutical analysis.

There are some papers examining the efficiency of chemistry combined into pharmacy teaching already. Structurally based therapeutic evaluation (SBTE) is such a valuable and practical teaching approach in medicinal chemistry introduced by Alsharif et al.[12] It mainly emphasizes the relevance of chemistry to the practice of pharmacy and structurally based therapeutic evaluation. Therein, students are required to identify the chemical/structural basis for the pharmacological and therapeutic action of drugs, and then to analyze and explain why a drug works. Specifically, the goal of CST is to translate chemical and structural understanding into predicting chemical properties, and then to speculate on its possible analysis method.

According to the connectivism theory by George Siemens,[13] in the digital era where knowledge and information increase exponentially, to know is in fact to be connected. That is to say, the learning process is analogous to weaving a web, and namely, when we are learning something new, we are actually trying to put the new knowledge into our existing networks by adding new nodes. Therefore, the more connective the built knowledge network is, the more holistic our understanding will be. Connectivism theory has already been incorporated in medical education and exhibited positive influences.[14] The same principle can also be applied in pharmaceutical analysis. Repeated employment of CST is beneficial to the efficiency of memory retrieval in related courses.

In summary, CST can free students from heavy memory burdens, enable students to hone skills in synthesizing information, thinking logically, and analyzing problems independently. Also, it can be utilized in other curricula, such as organic chemistry, medicinal chemistry, and spectrum analysis.

■ THE DISCOVERY OF CST

After analyzing and summarizing the contents of pharmaceutical analysis, it was found that all chapters in the textbook[10] are arranged with the following logic: identification test, impurity test, assay, biopharmaceutical analysis, and analysis method validation. Inspired by the fact that pharmacological activities are always determined by the chemical structure, we might conclude that the learning materials of the identification test, impurity test, and assay are also closely related to drugs' chemical structures. As such, we developed this novel and effective CST method based on our long-term teaching experience which has been practically applied in our pharmaceutical analysis course. The key idea of CST is to focus on the chemical structures of medicines due to the basic principle "properties are determined by structures". For instance, the concrete identification, impurity test, and assay procedures are likely to be inferred by logical deduction. The whole process of CST is designed as "observing structures → speculating properties → determining analysis methods → verifying with textbook and the ChP" as shown in Figure 1. This process has been proven to be conducive to both students and teachers. As such, when learning a new drug, students can actively speculate possible analysis methods based on a drug's chemical structure and then verify the correctness of the inferred methods with ChP and the textbook.

The creative teaching mode can provide meaningful references for other related courses such as organic chemistry, medicinal chemistry, spectrum analysis, and pharmaceutical synthesis, to just mention a few, as displayed in Figure 2.

■ THE APPLICATION OF CST

After identifying the fundamental logic of the pharmaceutical analysis course, we designed some teaching steps to implement

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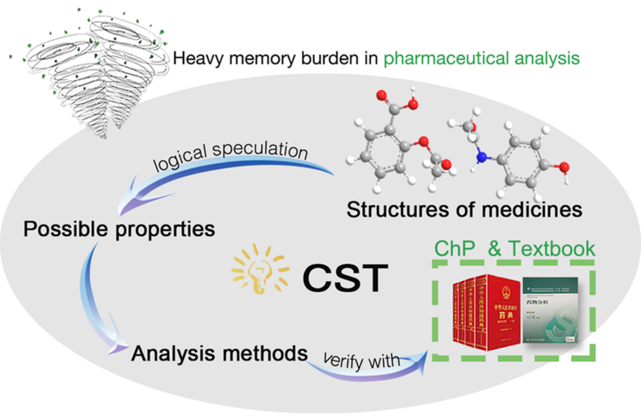

Figure 1. Graphical representation of the CST method.

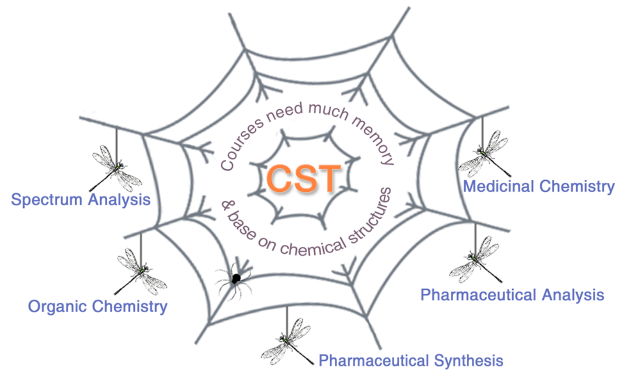

Figure 2. Possible extended curriculum of the CST method.

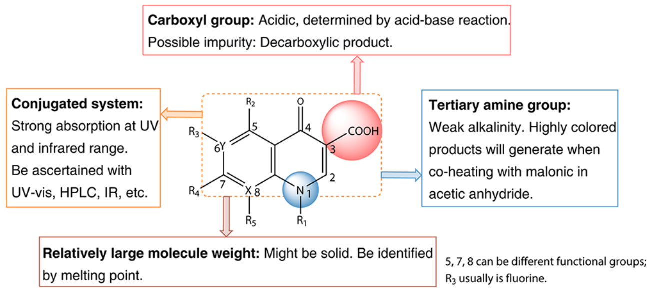

Figure 3. Expression of quinolone CST method.

this method. When lecturing on the pandect, we generally introduce the CST method to make students have an initial impression on CST. When stepping into lecturing on the subpandect, we choose some chapters as examples to demonstrate CST in detail. Then, all students are encouraged to take part in the design process for the remaining chapters, which will be beneficial to train their critical-thinking ability, oral expression, and logical reasoning. The typical application of CST in pharmaceutical analysis is detailed as follows.

First, we guide students to become familiar with the basic process of CST. They are trained to deduce possible physical and chemical properties according to the elementary structures of medicine, and then further to explore possible impurities and analysis methods with preliminary assumptions. We then let students summarize analytical methods from the aspect of identification, impurity test, and assay, respectively, which should be verified using the corresponding knowledge mentioned in the textbook and the ChP to strengthen the impression of key points. At last, we guide students to draw a frame diagram for each drug to visualize and methodize piecemeal knowledge points on the chemical structures of drug. Following this process, students can review what they have studied and build a strong link among structures, properties of drugs, and analytical methods.

Take the CST expression of quinolones as an example. As demonstrated in Figure 3, we can see that quinolones have relatively large molecule weights and a carboxyl group which can form a hydrogen bond easily. On the basis of these observations, we can deduce that quinolones might be solids and can be identified by melting point. Due to the weak alkalinity of the tertiary amine group, quinolones can be converted into products that are brown, red, purple, or blue upon coheating with malonic acid in acetic anhydride. Nonaqueous titration is also applicable in quantitative analysis of quinolones. The carboxyl groups suggest that quinolones can be identified or assayed by acid−base reactions, and the decarboxylic product might be the source of impurity. In addition, we can make use of the reverse synthesis principle in organic chemistry to speculate possible impurities, such as the unreacted raw materials or intermediates or solvents.

Practice is crucial in learning. After introducing the key points of CST and taking several chapters as examples, students were told to practice CST by themselves. We have organized a few lectures where students and lecturer swapped their roles. Students were then divided into groups and designed the lectures with their peers. This has been proven to be an effective method in cognitive education and quality education.[1b] During this learner-based teaching process, we instructors should observe how students mastered the learning materials, gave timely feedback, and helped consolidate the key points in pharmaceutical analysis, while being resonant with correlated curriculums.

Also, the reasoning method and case study method along with inquiry teaching, heuristic teaching, discussion teaching, situational teaching, and other teaching methods can be applied synergistically to enhance students' interests and to encourage them to engage with learning materials. The general implementing process of these methods in practical teaching are illustrated as the following.

1. Carrying out a case study. Since the drugs introduced in pharmaceutical analysis are already widely used in society, we can discuss a piece of negative news of one drug in class. Then, the lecturer can guide students to make a connection between the learning materials and the society news by thinking about and analyzing what can cause a negative effect on drugs in society. For example, the transportation and storage of drugs which fail to follow GSP may lead to unwanted impurities, which could ultimately lead to dreadful tragedies. The case study is an effective method to highlight the question guide, to increase learning interest to a great extent, and to let students explore and solve problems actively.
2. Carrying out role exchange. According to the teaching course goals, teachers can combine deductive and inductive teaching methods in lectures by students themselves. For instance, in some lectures, the teacher can act as an organizer, an instructor, and a listener or a student, to encourage students to discuss and learn the relevant chapters actively as a lecturer by employing the

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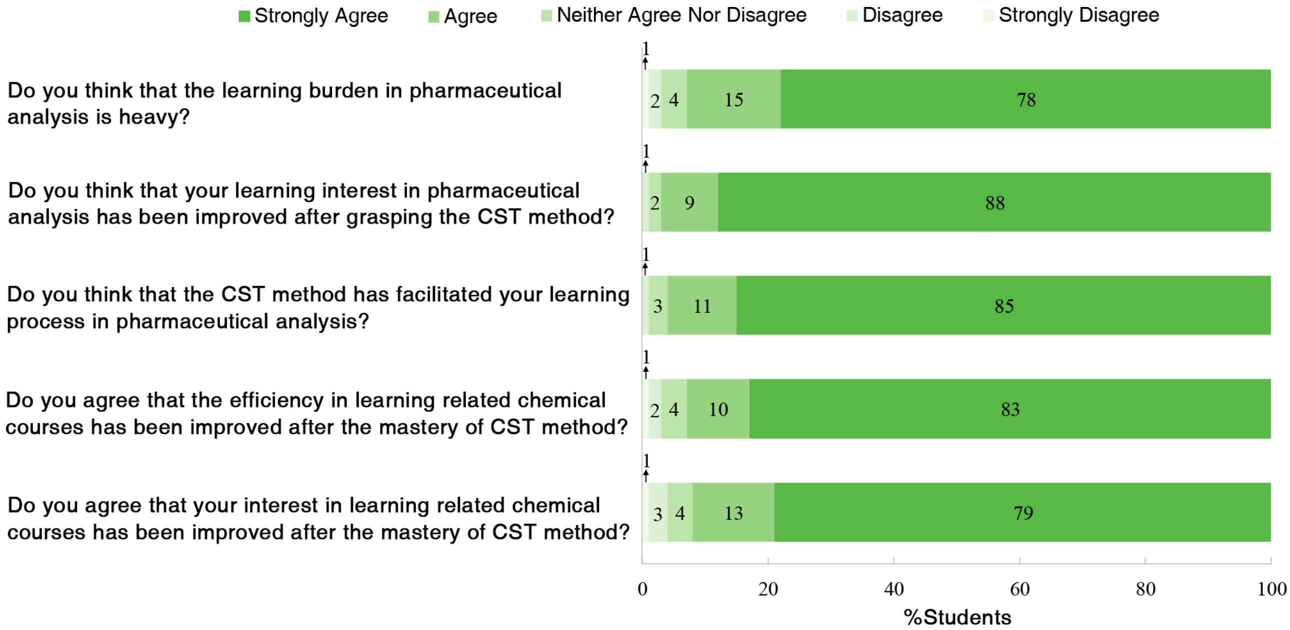

Figure 4. Results of the questionnaires for learning interest and efficiency about CST.

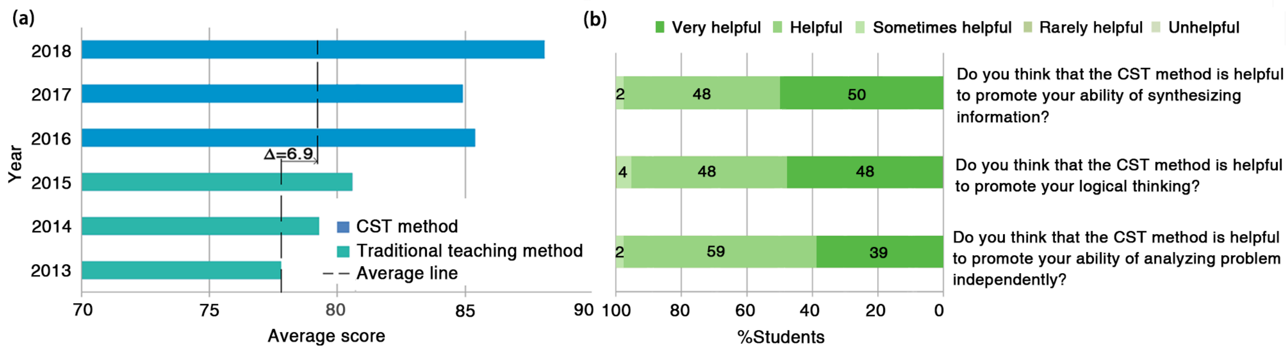

Figure 5. (a) Average scores of pharmaceutical analysis course in 2013−2018. (b) Results of the different ability questionnaires.

CST method. They can practice the abilities of organizing, oral expressing, and communicating, etc.

3. Carrying out frame teaching. Teachers can arrange students to do frame teaching based on the CST method in pharmaceutical analysis. Following the requirements of ChP, students need to make identifications and do an impurity test and assay based on the chemical structures of the drugs. The possible analytical method and properties can be demonstrated clearly by drawing frame diagrams to visualize all the key points. This frame teaching is beneficial for the learning process. It can also be used in other courses such as organic chemistry, analytical chemistry, spectrum analysis, medicinal chemistry, etc.

■ RESULTS AND DISCUSSION

Interest Survey

After completing the lectures to undergraduate majors in pharmaceutical engineering in 2016−2018, a questionnaire entitled "Improvement of pharmaceutical analysis learning quality in CST method" was distributed to them so as to obtain their opinions about the CST method. All 98 participant questionnaires were returned. Also, the questionnaire comprises five questions to evaluate the learning load, learning interest, and also the adoptability in other related chemical courses after the mastery of the CST method. All of the five questions range from strongly disagree to strongly agree, and the results are shown in Figure 4.

As demonstrated in Figure 4, at least 92% of the students answered these five questions positively (agreed or strongly agreed), and only no more than 8% students gave negative (disagreed or strongly disagreed) answers in general, which shows that the majority of students found benefits for themselves in learning pharmaceutical analysis with the CST method.

To be specific, 93% of the students believed that the learning burden in pharmaceutical analysis is really heavy. However, after the implementation of the CST method, nearly 96% of the students found their interest aroused in a more facilitated study process. This also revealed that more than 92% of the students found their efficiency and interest in other related chemical courses enhanced as well. These results reveal that the initial efforts in CST method implementation are successfully paid off as the majority of students gave positive answers.

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Teaching Effects

The effectiveness of CST in pharmaceutical analysis is investigated by some general factors, such as the average scores, the ability to synthesize information, logical thinking, and analysis of problems independent of students. These results can give some information about the CST teaching effects.

The students' average scores of exams from 2013 to 2018 were counted, and the results are shown in Figure 5. Within those 6 years, the CST method was used for pharmaceutical analysis teaching in 2016−2018, while the traditional script-oriented teaching was used in 2013−2015. From the results of Figure 5, the average scores have an increase after the implementation of the CST method, which is positive evidence to support the CST teaching effect.

Similar to the survey of learning quality about the CST method, the questionnaires regarding synthesizing information, thinking logically, and analyzing problems independently of student ability were employed to evaluate the teaching effects. Also, all 98 participant questionnaires were returned, and the results were summarized in Figure 5. For the synthesizing information ability, 98% students thought the CST method was helpful to promote this ability as well as the ability of cultivating independent analytical problem-solving. There were 96% students who thought the CST method could promote their logical thinking ability. So, it was found that most students thought the CST method had a positive teaching effect.

In addition to the improved performances on exams and the relevant abilities, CST also exhibited a great capacity for helping students increase good habits and qualities which are indispensable for their future career and life. First, through the CST process, students were trained to focus on the fundamental chemical structures of medicines; namely, they could see through the phenomenon to study the essence. Thereafter, students could gradually figure out the relationships between those seemingly different and diverse courses, which is analogous to assembling jigsaw puzzles, to map out a bigger picture.[15] In addition, the ability to identify properties and analyze methods from structures, in other words, to decipher the information contained within the medicines' structures, might help students to think logically, motivate learning interests, and increase confidence. Also, while employing CST, teachers can guide students to form the connections between new pieces of knowledge and the old knowledge network, which will eventually change their original modes of thinking. As George Siemens wrote in *Connectivism: A Learning Theory for the Digital Age*,[16] the pipe is more important than the content within the pipe. That is, today, to study is to link continuously instead of to always construct, which can ultimately weave a broader and broader web of knowledge, so that the implementation of CST can accelerate students' aquisition of new information while strengthening the old information in the meantime. They will also tend to engage with new learning materials actively and to become life-long active learners. Last but not least, CST can be used in other curricula with similar characteristics, such as organic chemistry.

Due to the heavy-duty memorization-based learning materials in the courses of pharmacy majors, it is very necessary to use a robust method which can help students to master learning materials quickly and more efficiently. CST has been proven to be effective to ease the burden in pharmaceutical analysis teaching and learning. Also, in the process of CST, students can get timely feedback when verifying their anticipated ideas with reference to the requirements of ChP. Together with other teaching methods, such as group learning, study efficiency can be further improved.[17]

■ CONCLUSION

In this paper, the CST method has been demonstrated on the basis of the problems encountered when lecturing on pharmaceutical analysis. CST was developed on the basis of the drug's chemical structure, and then this led to a series of logical inferences as far as different analytical methods. The CST method can help students and teachers ease the learning and teaching burden which result from the complex and scattered knowledge points existing in pharmaceutical analysis. Our experience and practice have proven that the CST could not only let students master key points more easily, spontaneously, and efficiently but also could help them engage with learning materials more, learn more actively, and interact with faculty and their peers more. Given the similar characteristics, CST can also be applied in other courses. For example, in organic chemistry, CST can help to speculate chemical properties of structures. In spectrum analysis, CST can be used to demonstrate how to determine different chromatographic behaviors and spectral characteristics. We believe that CST can be popularized among the chemistry courses whose knowledge systems are diverse and memorization-based and focus on the relationships between chemical structures and properties. In conclusion, CST is an effective teaching method suitable for learners and lecturers who have chemistry backgrounds to learn and teach pharmaceutical analysis and other related chemistry curriculums.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: huizheng@hznu.edu.cn.

ORCID

Hui Zheng: 0000-0003-0785-6728

Qiang Sun: 0000-0002-4183-1260

Jun Cao: 0000-0003-1224-0071

Notes

The authors declare no competing financial interest.

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