A Flipped-Classroom-Based Teaching Model for the Principles of Chemical Engineering Course

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Abstract: *This paper proposed the application of a flipped classroom model for teaching the Principles of Chemical Engineering course, in which universal problems exist, such as the considerable number of formulas, the abstract theoretical knowledge, the difficulty to master, and the students' insufficient learning motivation. This teaching model boosts the students' interest in learning the course and develops their capabilities of independent learning and thinking, as well as innovation, by virtue of the pre-class preparation made by the students, knowledge internalization and absorption in class, homework and extended learning task after the class, as well as the online and offline interactions between the students and the teacher. Moreover, when combined with a dynamic teaching evaluation, this model has also been proven effective in enhancing the students' learning motivation. Lastly, this teaching model has also been confirmed to be applicable to students of any levels of expertise for this course.*

Keywords: *Flipped classroom, Principles of chemical engineering, Unit operations*

The "flipped classroom" is a new teaching model.[1, 2] Different from the traditional in-class teaching model, the flipped classroom model features a pre-class preparation as well as in-class knowledge internalization and absorption by the students, in which the class session is used for teacher-student communication and interaction, including explanation (Q&A session) of key and difficult points, application and expansion of knowledge, answering questions, as well as knowledge exchange and discussion, through which good results can be expected to be achieved. [3-7] With the development of information technology and the internet, the application of the flipped classroom model in the field of education gradually becomes feasible and realistic.[8-12]

The Principles of Chemical Engineering is a basic course designated to the chemical engineering majors and other related majors, and is also a course that "bridges" the basic courses, such as University Physics, Advanced Mathematics, and Basic Chemistry, with the specialized courses, such as Separation Engineering and Reaction Engineering.[13, 14] Moreover, it is also a basic core course serving as a transitional medium from a basic course to a specialized course of Engineering Science. This course is aimed at developing the concept of engineering among students, and enhancing their ability to solve complicated engineering problems. By learning this course, students must master the basic principles of the chemical transfer process and have the preliminary ability to apply what they have learned to deal with practical engineering problems, and this course can develop their innovation consciousness and capability.

Principles of Chemical Engineering involves many unit operations, most of the students think this course is difficult to learn, leading to the lack of motivation. Besides, the numerous abstract formulas in the syllabus make the course even harder to comprehend and learn. Hence, to improve the current teaching of the Principles of Chemical Engineering, to facilitate the students to learn more effectively, and to enhance the teaching quality, we actively explores the application of the flipped classroom model into the teaching of the said course.

1. Construction of the flipped classroom model

The Principles of Chemical Engineering involves the basics of hydromechanics, fluid transport, mixing and agitation, filtration, sedimentation, fluidization, heat transfer, evaporation, gas absorption, liquid distillation, liquid-liquid extraction, adsorption, and other mass transfer and separation methods, solid drying and other unit operations. At the onset, students will be unable to realize the transfer principle shared by the unit operations, nor comprehend the research methods they share, as they always feel these chapters are independent of each other, and are barely interrelated, making them very hard to learn. Generally, in the traditional classroom teaching, teachers are accustomed to explaining each chapter by its different aspects, for instance, from "The Principles of Unit Operations", then to "The Equipment" and "Qualitative and Quantitative Analysis as Well as Calculation". But the students think of the unit operation equipment and equipment structure as abstract entities that are insipid and beyond comprehension. Based on these facts, the course teaching team vigorously explored the application of the flipped classroom model into the Principles of Chemical Engineering from three teaching processes —— pre-class preparation, in-class teaching, and after-class extensions.[15]

1.1 Pre-class preparation

The Principles of Chemical Engineering is a national-level fundamental course. After years of improvement,

many students have been increasingly benefited by it. One of the measures taken by the teaching reform by the teaching team is the web-based teaching platform co-developed by the university and Wisdom Tree (zhihuishu.com), in which the learning materials, such as the course calendar, courseware, teaching course, and learning task, are released to the students before the class, to meet their needs for online learning. Related teaching videos are also produced by the team's teacher in Wisdom Treeat a filming studio. The length of the video is 10-15 minutes, and the content includes key and difficult points, the structure of the equipment (students think they are abstract because they have never seen it), principles of each unit operation, related calculations, and so forth. The teaching videos present the phenomena appearing in the equipment structure and engineering application to the students in a vivid and visual way to help them comprehend. Through these videos, the students are able to gain a perceptual knowledge of the principles and equipment of unit operations before the in-class teaching, which arouses their interest in studying further. For example, the video about the structure of centrifugal pump and centrifugal pump air binding vividly displays the structure of a centrifugal pump and explains the causes behind the air binding, the methods to avoid the air binding, and the cautions pertaining to the operational processes like pump activation. Additionally, these teaching videos allow students to watch and learn it repeatedly, which effectively avoids the "glancing off" of some points due to the time limit in the traditional teaching process, and the students can overcome the difficulty in conducting a deep learning session by watching these videos repeatedly. The learning tasks are set by chapter to help the students learn. Moreover, the teaching video also sets some moderately difficult pop-up questions for students to think and answer in the learning process. For example, how many forms of fluid flows are there in the basics of hydromechanics? What is the difference between them? What are the essential differences? Students answer these questions on the web-based teaching platform: if they fail to correctly answer pop-up questions, they can play back the videos immediately until they completely figure it out. The digital web-based teaching platform will record the time they've spent on watching these videos, check learning progress, and help teachers urge their students to study further.[16] Moreover, the platform directly grades the day-to-day performance of these students according to their completion of learning tasks.

1.2 In-class teaching

On the web-based teaching platform of Wisdom Tree, students learn from the teaching video online and master most of the teaching contents before class. Therefore, classroom teaching is naturally conducted offline. At first, the teacher checks the outcome of the students' pre-class preparation and randomly air some questions at the students, which helps urge the students to learn independently before the class and ensures the learning outcome. How students answer these questions is one of the bases of judging their day-to-day performance. In addition, the teacher of the in-class teaching offers his/her comments according to their answers and the completion of the learning task on the web-based teaching platform, focuses on explaining the key and difficult points of each chapter, exploits the advantages of classroom teaching to the fullest, and helps students comprehend and absorb key and difficult points more effectively. For some easily-misunderstood or confusing knowledge points, the teacher designs some questions again to let students conduct group discussion, and controls the time of this process, e.g., 6-8 minutes each question. For instance, in the discussion on the comparison between the centrifugal pump air binding and cavitation and the influence of rotational speed on centrifugal pump characteristic curve, the questions that students discuss include: "What are the causes behind centrifugal pump air binding and cavitation?", and "What is the consequence of revolving speed influencing the characteristic curve?" Students discuss in groups, while the teacher takes an active part in it, supervising and guiding the students during the discussion. At last, the teacher makes his/her comments and summaries. The in-class teaching process integrates the traditional classroom teaching and the flipped classroom model, boosts the students' awareness of independent learning, and makes it easier for the teacher to learn about the students' mastery of the knowledge to enable the design of a more purposeful and targeted teaching.[17, 18]

1.3After-class assignment and extended application

To reinforce the knowledge learned by the students, the teacher assigns homework or extended assignments to the students according to the content of each chapter after the in-class teaching is completed. Assignments may come from textbook exercises or self-test questions, while extended assignments are relatively flexible and unconventional, preferably the problems they encounter in everyday life. For instance, knowing that the domestic water and gas supply are from the waterworks or gasworks, and that the pipelines are to enter every floor and every household after the water or gas supply enters the residential community from the main piping, how can one reasonably arrange the pipelines to ensure that each household gets the water or gas supply? Such cases make students actively think and discuss the piping layout and the principles of the reasonable arrangement of main and branch piping. Finally, each student makes an individual design scheme and submits it to their teacher, then the teacher checks and comments on their homework in time. The design scheme in the extended assignment is also taken as one of the bases for evaluating their day-to-day

performance. Principles of Chemical Engineering is a highly practical engineering discipline. The teaching process of after-class knowledge extension makes the students feel what they have learned is useful and able to solve practical engineering problems in everyday life or in the chemical industry, which undoubtedly boosts their interest and learning motivation.[19, 20]

2. The specific implementation of the flipped classroom model in Principles of Chemical Engineering

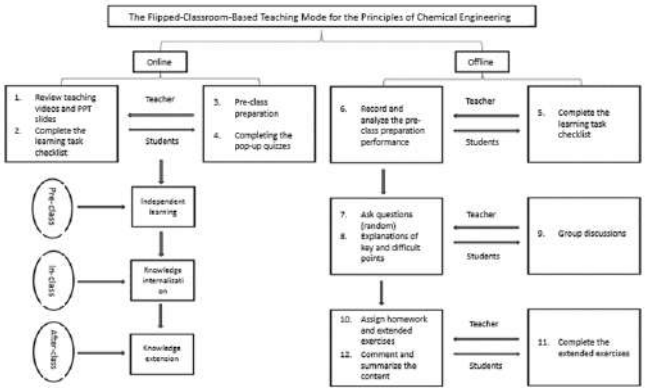

Chart -1: The implementation process of the flipped classroom model in Principles of Chemical Engineering

The specific implementation of the flipped classroom model in the teaching process of Principles of Chemical Engineering is to put online and offline learning activities throughout the following three teaching processes —— before-class, in-class, and after-class teaching. Students and teachers collaborate to complete each teaching task.[19, 20] The specific implementation process is laid out in Figure 1, and its plan design, taking the teaching design of the centrifugal pump as an example, is as shown in Table 1.

3. Teaching evaluation and satisfaction survey

The evaluation for the flipped-classroom-based teaching model for the Principles of Chemical Engineering consists of two parts —— day-to-day performance (50%) and the final exam (50%). The day-to-day performance is divided into three parts: completion of independent learning tasks (automatically-generated statistics by the web-based teaching platform) with teaching video (online), attendance, and completion of offline homework and knowledge extension. The day-to-day performance takes up 50% of the total points, and is meant to motivate the students to learn independently throughout the semester and effectively avoid the drawback of having only one final exam to grade the overall performance.[21] The final exam is conducted in the form of a closed-book exam, just like the traditional teaching. Finally, the total points obtained by the students is calculated by adding the day-to-day performance and final exam performance according to their designated proportions, and then the teacher comprehensively assesses their academic performance and summarizes the teaching outcome.

Table 1: The flipped classroom model-centrifugal pump teaching plan

Teaching process	Teaching tasks	Details of learning activities for the students
Before class	1.Independent learning; 2. Complete learning tasks like pop-up questions.	Watch teaching video and courseware
In class	Group discussion	Questions: 1. What form of energy is needed for the pipeline to complete the liquid delivery? How factors like fluid properties and pipeline structure influence the pipeline characteristic curve? What is air binding? How to avoid air binding? 2. How does centrifugal pump work? What is the function of each major componentof a centrifugal pump? Why is the backward-curved fan commonly used? 3. What are the characteristic curves of a centrifugal pump? How to measure that? What are influencing factors on the characteristic curve? What are the implications of the characteristic curve for operating a centrifugal pump? 4. How to identify the operating point of a centrifugal pump? How to adjust the flux? 5. How to determine the installation height of a centrifugal pump? What is cavitation? How to avoid cavitation?
After class	1.Complete exercises and self-test questions; 2. Complete extended assignment.	How to choose a centrifugal pump? What are the combined operations of a centrifugal pump? How does the characteristic curvechange after the combination? How to choose the combined operations for a centrifugal pump?
	Teaching evaluation	Comprehensive assessment, summarize teaching outcome

In the flipped classroom teaching, the traditional teaching pattern, where "the teacher teaches and the student learns" no longer exists, and the roles played by the teacher and the students have changed. |In this paper, the students' satisfaction with the flipped classroom model was surveyed, and is shown in Figure 2 It can be observed from Table 2 that the implementation of the flipped classroom model is well received by the students, as most of them accept the flipped classroom model.

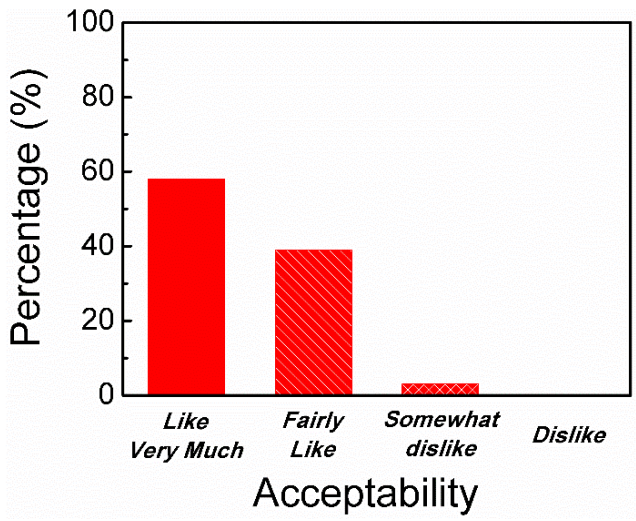

Chart -2: Acceptability of the flipped classroom model

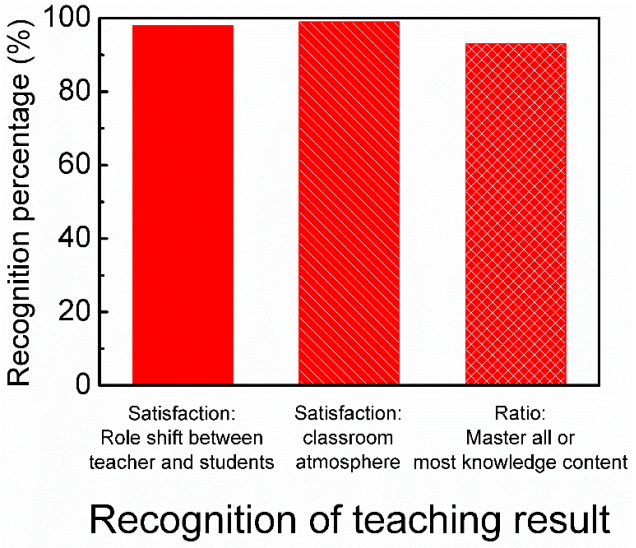

Chart -3: Recognition of the teaching outcome of the flipped classroom model

The purpose of carrying out the flipped classroom model is to guarantee the achievement of the teaching objectives. Besides taking how do students feel into consideration, it is necessary to further survey the teaching results, and these results are shown in Figure3. Figure 3 shows that most of the students think classroom teaching is effective.

Compared with the traditional teaching model, the flipped classroom model has apparent advantages. Whether this teaching model is applicable to teaching is determined by whether the students can learn what is taught, i.e., their level of perception. To explore this further, at the end of the implementation, a relevant survey has been conducted on the class that has used this teaching model, please refer to Figure 4 for the results. The findings in Figure 4 show that the students generally recognize the learning outcome of the flipped classroom model.

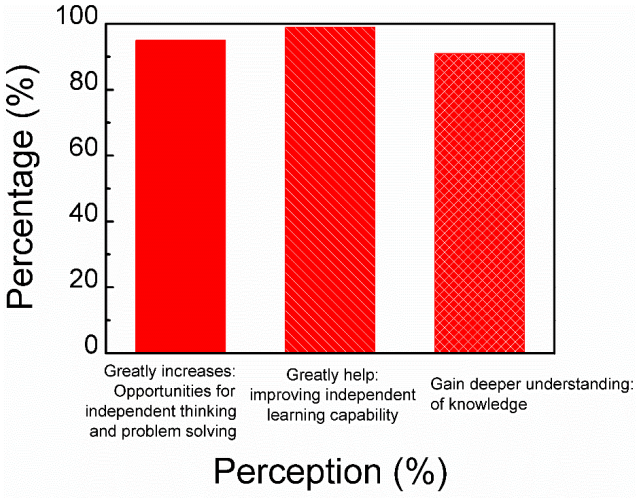

Chart -4: The perception level of the learning outcome of the flipped classroom model

4. Conclusions

The application of the flipped classroom model to the teaching of the Principles of Chemical Engineering has therefore been proven to revolutionize the "inculcation" knowledge imparting method that prevails in the traditional classroom teaching, fully arouse the students' interest in learning this course, boost their independent learning motivation, and enhance their abilities to analyze engineering problem, summarize, improve, and innovate. This teaching model has also enabled students to effectively comprehend the content taught in the said course and improved their learning efficiency and quality of classroom teaching with visual teaching through the videos provided for pre-class preparation, the group discussion, the in-class analysis, the after-class homework and knowledge extension, as well as the dynamic assessment ofthe student's day-to-day performance.

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