Advances in Educational Technology and Psychology (2023)
Clausius Scientific Press, Canada

DOI: 10.23977/aetp.2023.071403
ISSN 2371-9400 Vol. 7 Num. 14

Application of Rain Classroom and BOPPPS Model in Teaching Design of Thermodynamics and Fluid Mechanics—A Case Study on the Second Law of Thermodynamics

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Keywords: Teaching design, rain classroom, BOPPPS, second law of thermodynamic

Abstract: This study explores the utilization of rain classroom, in conjunction with the BOPPPS instructional model, for the teaching design of Thermodynamics and Fluid Mechanics. Focusing on the second law of thermodynamics, this paper presents a comprehensive case study via an innovative approach employed in the classroom. The learning situation analysis of the students is first carried out to understand the limitations of traditional teaching method. Teaching design based on rain classroom and BOPPPS is further conducted in the sequences of pre-class preparation, bridge-in, objectives, pre-assessment, participatory learning, post-assessment and summary. The practical teaching effects indicate that, the combined use of rain classroom and the BOPPPS model promotes active participation, real-time feedback, a deeper understanding of complex thermodynamic principles, significant political and ideological education effects. Above technology-enhanced teaching method can provide valuable insights for educators seeking to optimize the pedagogical strategies in science and engineering disciplines.

1. Introduction

Rain classroom is an online education platform designed by Tsinghua University and XuetangX to facilitate remote learning and teaching. It offers a wide range of features for educational institutions, teachers and students to engage in virtual classrooms. This platform supports live online classes, content management, student tracking and interactive tools, making it a comprehensive solution for online education. It promotes interactive learning and collaboration among students and teachers in a digital environment, enhancing the remote learning experience. In recent years, rain classroom has been extensively applied as a blending approach of mobile learning and formal classroom learning in Engineering Thermodynamics [1], Offshore Oil and Gas Engineering [2], Organic Chemistry [3], College English [4] and other courses.

The BOPPPS model is a structured approach that aims to create an engaging and effective learning environment. It involves students in various stages of the learning process, and ensures that instructional objectives are clear and achievable. The acronym BOPPPS stands for bridge-in, objectives, pre-assessment, participatory learning, post-assessment and summary six components. Di et al. [5] carried out ideological and political teaching design in Chemical Engineering Thermodynamics based on BOPPPS model. Zhang et al. [6] improved the BOPPPS teaching model and utilized it for the online and offline blended teaching of Engineering Thermodynamics in combination with "ideological-political education" and "flipped classroom". In general, the BOPPPS teaching model is designed to create a student-centered and effective learning environment that fosters engagement, comprehension and retention of course material.

Thermodynamics and Fluid Mechanics is a core and compulsory course for students majoring in Mechanical Design, Manufacturing and Automation of Qilu University of Technology. It is an interdisciplinary engineering course that explores the fundamental principles governing the behaviour of energy transfer and fluid flow transfer in engineering systems. During the course learning, the students may encounter some common difficulties such as complicated concepts and equations, solid mathematical foundation, the gap between theory and practical application. Therefore, traditional classroom teaching methods are no longer able to meet the diverse and complex requirements of modern high education. The objective of the present paper is to improve the teaching quality of professional courses by integrating BOPPPS model and rain classroom into the Thermodynamics and Fluid Mechanics, taking the second law of thermodynamics as an example.

2. Learning Situation Analysis of the Second Law of Thermodynamics

The second law of thermodynamics is a fundamental principle in the field of thermodynamics that has far-reaching implications in various scientific and engineering disciplines. After learning the first law of thermodynamic, the students have acquired a certain foundation in thermodynamics. However, the knowledge relevant with the second law of thermodynamics can be challenging for students due to its abstract nature and counterintuitive principles. The idea that natural processes tend to move toward greater disorder contradicts our everyday observations, making it difficult to accept. Moreover, the second law's multidisciplinary nature, historical development, and the presence of paradoxes and misconceptions further compound the difficulties in its comprehension. Additionally, the mathematical expressions and complicated equations used to describe the law can intimidate students, requiring a strong foundation in mathematics. To overcome these challenges, BOPPPS model and rain classroom can be applied to provide a systematic and adaptable framework for optimizing the teaching and learning experience.

3. Teaching Design and Implementation based on BOPPPS and Rain Classroom

3.1 Pre-class preparation via rain classroom platform

One week before the class, online national premium course teaching resources recorded by Tsinghua University (https://www.bilibili.com/video/BV1n4411y73f?p=17) and Xi'an Jiaotong University (https://www.bilibili.com/video/BV1pW411N7Fn?p=23) on the topic of the second law of thermodynamics are selected and delivered to students through the rain classroom platform. In order to provoke profound contemplation among students on the implications of the second law of thermodynamics for energy conservation and environmental sustainability, political education video resources named "Earth Hour" (http://tv.cctv.com/2022/03/26/VIDEYmziskHAuAxzYrTSJTVT220326.shtml) and "Energy and National Security" (https://www.bilibili.com/video/BV1nL411Q7hv

/?spm_id_from=333.337.search-card.all.click) are also delivered to students via the rain classroom platform. Teachers can promptly monitor students' pre-class independent learning progress, summarize pre-class study situations, and use the outcomes of this phase as the benchmark for evaluating pre-class learning outcomes.

3.2 Bridge-in

Bridge-in allows students to feel comfortable and get settled before launching into the content. In this part, it is started off by sign-in function of rain classroom. The teacher can check the attendance and ask students to answer the questions "is it possible to create a machine (a perpetual motion machine of the first kind) that can continuously perform work without consuming any energy from external sources? Why". Based on the prior knowledge relevant with the first law of thermodynamics, most students can give a definite answer "no, because such machine violates with the first law of thermodynamics". Following comes the second question "is it possible to create a machine (a perpetual motion machine of the second kind) that can convert all externally absorbed heat energy into useful work". Until now, the lesson tone is set to the second law of thermodynamics and the students' attentions are gained.

3.3 Objectives

Based on the second question asked in bridge-in part, the study objectives of this class are determined. The knowledge objective of this lesson is to ensure that students grasp the directionality of natural processes, the essence and two typical statements of the second law of thermodynamics, and the relationship between the first law and second law of thermodynamics. The skill objective is to enable students to apply the second law of thermodynamics to determine the directionality of macroscopic processes involving heat phenomena, using it to solve and explain problems and phenomena in everyday life and engineering applications. Furthermore, the ideological and political objective is to cultivate students' abilities in technological innovation, strengthen their awareness of engineering ethics, and inspire their sense of patriotism and mission in serving the country through technological advancements.

3.4 Pre-assessment

The pre-assessment in the BOPPPS model is an initial evaluation or diagnostic tool used before a learning lesson, which helps teachers gauge the pre-class preparation effect and existing knowledge of the students related to the upcoming topic. In this class, with the help of class test function of rain classroom, one single choice question is published and sent to students: "it is common experience that a cup of hot water left in a cooler room gradually cools off. Is it possible for a reverse process to take place - the hot water getting even hotter in a cooler room as a result of heat transfer from the room air, and why"? This test is relevant to students' real-life, and the voting results from students indicate that they have answered correctly. They all know that this reverse process never occurs based on their real-life experiences. However, there is a general consensus that they are unclear about the underlying reasons behind these phenomena. The reverse process would not violate the first law of thermodynamics, provided that the quantity of energy lost by the air is equal to the energy gained by the water. The first law does not impose constraints on the direction of a process, but compliance with the first law does not guarantee the feasibility of the process. To address this limitation in the first law's ability to determine process feasibility, another fundamental principle named the second law of thermodynamics is introduced.

3.5 Participatory learning

Participatory learning involves actively engaging students in the learning process, in order to foster a more interactive and student-centered classroom environment. It encourages students to actively participate, ask questions, discuss topics, and collaborate with peers, rather than passively receiving information. Based on the question published in pre-assessment, we know that a process must satisfy both the first and second laws of thermodynamics to proceed. The second law of thermodynamics reveals that the process moves towards the direction of energy degradation. The essence of the second law is that all real macroscopic processes in the natural world related to thermal phenomena are irreversible.

Now, the students are wondering the detailed expression of the second law of thermodynamics due to its significance. In this part, the teacher presents two classical statements of the second law by storytelling teaching method, thus the students can perceive the learning process more easily and effortlessly. In 1824, the French engineer Nicolas Léonard Sadi Carnot introduced the famous "Carnot theorem" in "Reflections on the Motive Power of Fire", which identified the fundamental pathway to improve the efficiency of heat engines. Between 1840 and 1847, through the efforts of scientists like Mayer, Joule, and Helmholtz, the first law of thermodynamics and general laws of energy conservation were established. In 1850, Clausius re-examined Carnot's work. Based on the common knowledge that heat does not spontaneously flow from a colder body to a hotter, Clausius gave the first rigorous definition of the second law of thermodynamics: "it is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body". In 1851, Lord Kelvin independently derived another definition of the second law from the perspective of heat-to-work conversion, similar to the statement given by Planck. The classical Kelvin-Planck statement is "it is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work". This lesson also incorporates ideological and ethical elements during the story-telling process. The story and achievements of eminent scientists associated with the second law of thermodynamics can cultivate scientific spirit and foster students' resolute determination to pursue the truth.

In order to demonstrate the complete equivalence of the two aforementioned statement based on proof by contradiction, the teacher use class whiteboard function of rain classroom to realize real-time recording of blackboard-writing. To better understand the implications and applications of the second law of thermodynamics, this class encourages students to discuss and debate by random grouping function of rain classroom. The teacher publishes the open question "what is the relationship between the first law and the second law of thermodynamics" inserted into the courseware to the class. After in-depth discussions, each group can submit the answers and share their insights with other groups. The teacher gives comments on the students' insights and provides additional answers to this question. The first law of thermodynamics reveals the energy conservation during the energy transformation and heat transfer from the perspective of energy quantity. The second law of thermodynamics elucidates the directionality of processes from the perspective of energy quality, thus addressing the second question raised during the bridge-in phase. It is impossible to create a perpetual motion machine of the second kind, which can guide students to comply with scientific laws in the pursuit of human ambition, scientific skepticism, ethical responsibility, and educational value.

Although two laws of thermodynamics were established many years ago, their theoretical foundations remain critical for current high-tech domains. Searching from library database resources, the engineering applications of these two thermodynamic laws in cutting-edge areas are introduced to students, including fuel cells, advanced heat exchangers, the human respiratory system, renewable energy sources and ceramic generators. The students are also encouraged to search more advancements in scientific research relevant with two laws of thermodynamics after class, thus enhancing their international perspectives and fosters awareness of technological innovation through exposure to cutting-edge disciplinary knowledge.

3.6 Post-assessment

The primary purpose of post-assessment is to evaluate whether students have achieved the stated learning objectives and to measure their comprehension of the knowledge covered during the lesson. At this stage, we primarily utilize the rain classroom smart teaching tool to conduct in-class and after-class quizzes, with a focus on assessing students' understanding of the second law of thermodynamics. The first in-class quizzes sent to students via rain classroom is "is it sufficient to ensure that a natural phenomenon or an engineering process will definitely occur as long as it complies with the first law of thermodynamics". Based on statistics results from rain classroom, it can be observed that all students are able to provide the correct answers. This indicates that all students demonstrated a solid understanding of the topic. Then, the second quizzes is published: "the first law of thermodynamics states that the total energy remains constant during energy conversion and transfer processes. Why do we still encounter energy crises and advocate for energy conservation". The second quizzes is a more complicated question, requiring students to proficiently master and apply the second law of thermodynamics to solve problems. Therefore, the answers to the second quizzes can be submitted via rain classroom in 3 days after this class, based on which the teacher can provide further after-class guidance.

3.7 Summary

Summary is the final phase of the instructional design framework. In this phase, the teacher can highlight the critical information, emphasize the content relevance and connect it to the stated objectives. In this lesson, the teacher reviews the directionality of natural processes, the essence of the second law of thermodynamics, two classical statements of the second law of thermodynamics, as well as the relationship between two laws of thermodynamics. Specifically, from the perspective of students majoring in Mechanical Engineering, it is imperative to align with scientific laws before engaging in mechanical design and calculation. Energy not only possesses quantity but also quality. Efficient utilization and cascade use of energy resources play a pivotal role in energy conservation and consumption reduction, which in turn guards the national energy security.

3.8 After-class homework

Tailoring to the specificities of the students' disciplines, after-class homework on the topic of "Engineering Applications of the Second Law of Thermodynamics" is published on the rain classroom platform. The students in 5 groups are encouraged to discuss and explore how the second law of thermodynamics can be professionally applied to the design and optimization processes of some devices. In the following lesson, each group will have 3 minutes to deliver a presentation on this topic in the form of flipped classroom.

4. Conclusion

The application of rain classroom and BOPPPS instructional model throughout the entire learning cycle has proven highly effective to achieve the teaching objectives. Rain classroom facilitates interactive and engaging online learning, allowing for real-time assessments and participation tracking. According to feedback data from rain classroom platform, the completion rate of pre-class preparation can be 95% with the help of teacher's supervision. During the class, the combination of rain classroom and BOPPPS enhances student engagement, promotes deeper comprehension, and provides a valuable platform for teaching complex thermodynamic principles effectively. After class, the teacher can timely check the class learning situation and reply students' comments on the courseware details page. In addition, the accumulation and statistics of rain classroom platform can provide data support and theoretical foundation for the continuous optimization and reform of teaching processes in the future.

Acknowledgements

This research was carried out with financial support of Teaching Research Project from Qilu University of Technology (Shandong Academy of Sciences) (Research on the Construction of Ideological and Political Demonstration Course of "Thermodynamics and Fluid Mechanics" Targeting National First-class Major, 2022zd03; Research on Graduate Teaching System for Mechanical Engineering in the Context of Integration of Science, Education, Industry and Perspective of New Engineering), for which due acknowledgement is given.

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