Talking about the Design of Thinking Questions—Taking the Course of Physical Optics as an Example

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Abstract. The design of thinking questions is an important part of teaching activities. Thinking questions are the supplement and extension of classroom teaching contents, which plays a significant role in improving teaching effects and qualities. In the course of Physical Optics, this paper has actively explored and practiced the design of thinking questions. According to different teaching contents and teaching objectives, we carefully design pre-classroom, classroom and after-classroom thinking questions, which is very helpful for deepening students' understanding of important physical concepts, guiding students to explore relevant unknown areas, and training students to apply what they have learned to solve practical problems.

Introduction

In traditional teaching, students usually are in a state of passive acceptance. Teachers pay great attention to knowledge acquisition of students, and often pay little attention to the cultivation of students' ability. While modern teaching philosophy advocates that all teaching activities should be student-centered, and the most important teaching purpose is to cultivate students' innovative thinking and innovative ability. Since the 1990s, developed countries such as the United States, Germany, and the United Kingdom have vigorously advocated research-based teaching in research universities, cultivating students' innovative abilities. In 1998, the well-known research report published by the U.S. Boyer Commission, "Reinventing Undergraduate Education: A Blueprint for America's Research Universities," clearly pointed out that research-oriented teaching should be regarded as the basic requirement for undergraduate teaching. The reform of domestic universities is relatively lagging behind. In 2005, the National Ministry of Education issued "Several Opinions on Further Strengthening Undergraduate Teaching in Colleges and Universities", emphasizing that "we must actively promote research-based teaching and improve the innovative abilities of college students", and clearly putting forward the requirements for the development of research-based teaching. Since then, many universities have successively introduced various measures to accelerate the pace of teaching reforms, aiming at improving students' innovation abilities [1-3]. The design of course thinking questions is an important part of teaching reform.

Physical Optics is one of the most basic professional courses that science and technology workers must master in the fields of optics, optoelectronics, laser technology, and quantum optics. Through the study of this course, we can understand and apply optical fundamental theories and methods at a higher level, and obtain basis and ideas for innovative research in the field of modern optics. The physical optics curriculum is mainly based on the basic concepts, theories and methods of wave optics, and through the understanding of how the basic ideas of wave optics develop and improve in modern optics, so that students can master the basic theories and methods and get inspired. Based on the previous teaching reform results [4, 5], we have explored and practiced the research-based teaching mode in Physical Optics according to the characteristics of the curriculum and students. Here we mainly talk about the design of thinking questions. Practice has shown that well-designed
thinking questions play a positive role in deepening students' understanding of important physical concepts, guiding students to explore relevant unknown areas, and cultivating students' ability to apply what they have learned to solve practical problems.

**Understanding of Thinking Questions**

The design of thinking questions is an indispensable part of teaching activities [6]. Generally speaking, thinking questions are the supplement and extension of classroom teaching contents, applying to pre-class preparation, discussion of key contents in classroom, knowledge review and extending after class. It has characteristics of "purpose", "exploration", "inspiration", "openness", and so on. Among them, "purpose" means that the teacher has a clear purpose in designing the thinking questions, such as focusing on a certain key and difficult point, so as to deepen students' understanding of the learned knowledge. "Exploration" refers to designing a thinking question with one or several questions as a carrier, inspiring students to explore on their own, deepening the understanding and mastery of the knowledge they have learned in the process of solving problems, and at the same time, the innovation ability is well trained. "Inspiration" means that the purpose of thinking question design is to inspire students to consolidate, apply, and promote existing knowledge, stimulate students' desire for knowledge, and guide students to actively explore unknown areas. "Openness" means that the goal of thinking question design is not limited to the mastery of classroom teaching contents, but from the perspective of improving students' comprehensive ability, such as innovative thinking and innovation ability, scientific research ability, scientific spirit, cooperation ability, reading and writing ability, and so on.

**Designing of Thinking Questions**

The main purpose of research-based teaching is to improve teaching effects, and train students' comprehensive abilities. Therefore, research-based teaching is not only reflected in the classroom, but also in guiding students to study independently outside classroom. It should be throughout all teaching activities. So in the implementation of the research-based teaching in the course of Physical Optics, we have explored and practiced the design of thinking questions. According to different teaching contents and teaching aims, three kinds of thinking questions are well designed, which are pre-classroom, classroom and after-classroom thinking questions.

**Pre-classroom Thinking Questions**

Usually, thinking questions mainly include classroom and after-classroom thinking questions, and rarely mention pre-classroom thinking questions. In our research-based teaching, we introduce and carefully design pre-classroom thinking questions according to the idea that teaching activities should run through students' learning process. It is a prelude for the classroom teaching. Its main purpose is to stimulate students' interest in learning, to guide students to research and think about the main teaching contents before class, to facilitate students' understanding of key and difficult points in the classroom, especially to facilitate the discussion in classroom. When designing the pre-classroom thinking questions, we paid attention to the two aspects of "guiding" and "interesting".

**Guiding.** "Guiding" means that the purpose of the design of pre-classroom thinking questions is to guide students to conduct preliminary study of the main teaching contents before class. For example, in the section of "Fraunhofer diffraction of circular holes", the content of the classroom teaching is mainly to introduce the diffraction of circular holes, and the diffraction of the opaque small circular plate is given by the Babinet principle of complementary screens. Due to the planning time restrictions, classroom teaching can not involve so many contents. Therefore, we design a thinking question before class: “What will happen when a big light beam encounters a small ink dot? Is the small ink dot insignificant?” and provide students with some relevant information, which would guide them to comprehensive understanding of historical background of the discovery of Airy's bright spot and scientists stories. It can not only promote students’ understanding of the key teaching content, but also expand the range of knowledge. For another example, in the section of
"Light scattering by medium", the Raman scattering will be briefly introduced in classroom due to the limitation of the planned class hours, but the related content is difficult to understand. In order to facilitate students' understanding of it, we design a thinking question: "What is Raman scattering? How does it be discovered? What are its characteristics? What is the difference between Rayleigh scattering and Raman scattering? What is Stokes wave and anti-Stokes wave?" Question-based thinking questions play a positive role in guiding students to learn before class.

**Interesting.** "Interesting" means that funs should be incorporated into pre-classroom thinking questions to stimulate students' interest in learning and spontaneously conduct research and thinking before class. For example, in the section of "Light dispersion of medium", in order to facilitate students' understanding of the physical mechanism and characteristics of dispersion in class, we design some pre-classroom thinking questions: “What’s the physical mechanism of rainbow? How about the color order of rainbow? At what time and in what direction is it easy to see rainbow? Why is rainbow seen to be curved on the ground? How can you see a circular rainbow? Have you seen a double rainbow? How does the double rainbow form? About the sequences of the second rainbow ribbons? Is the rainbow polarized? Can you make a rainbow yourself?” This series of questions greatly stimulate students’ desire to seek knowledge and prompt them to consult relevant literature. For another example, in the section of "Polarization of light", we design a question: "When you shoot a beautiful goldfish in a fish tank, you must have encountered the problem of reflected light. Is there any way to make the revivification of the beauty of the goldfish?" This question can promote students' understanding of reflection-related polarization in class.

**Classroom Thinking Questions**

Classroom thinking questions are an important part of classroom teaching. They usually are in forms of discussion and calculation of key and difficult knowledge points that should be mastered, which play a significant role in guiding students to think actively, activating the classroom atmosphere for interaction and communication. When designing classroom questions, we paid attention to the two aspects of “focus” and “discussion”.

**Focusing.** “Focusing” means that classroom thinking questions are mainly about teaching contents that students need to focus on. For example, in the section of "Diffraction of circular holes and resolution of optical imaging instruments", in order to deepen students' understanding of important physical concepts such as “diffraction limit” and “optical imaging limit resolution”, we design three calculation questions: (a) "It's the pupil diameter to determining eyes' ability to distinguish objects. The pupil diameter is generally 2~8 mm. Why do we usually say that the limit resolution of human eyes is about 1 angle cent?" (b) "The main mirror diameter of the Hubble telescope is 2.4 m, please calculate its limit resolution using visible wavelength of 550nm. Can it see a moth at a distance of one thousand kilometer?" (c) "Try to analyze the limit resolution of an optical microscope according to the resolution formula. Why is the limit resolution of an optical microscope about one-half of the light wavelength? How to further enhance resolution of microscopes?" These three questions can help students to understand the relationship of the limit resolution of optical imaging instruments and the diffraction limit, and deepen understanding of circular hole diffraction.

**Discussing.** "Discussing" means that the question is easy to carry out in the form of group discussion. For example, in the section of "Polarization of light", in order to help students to deepen the understanding of various polarized lights, we set up a question: "How to distinguish between natural light, partially polarized light, elliptically polarized light, circularly polarized light and linearly polarized light using a polarizer and a quarter-wave plate?" In the form of group discussion, it is welcomed by students. For another example, in the section of "Light dispersion of medium", in order help students to understanding the concepts of "phase velocity" and "group velocity", we set up a discussion topic: "Do you know how to measure the refractive index of medium? And in 1885, Michelson used the refraction law and propagation method to respectively measure the refractive index of liquid CS$_2$. While the results were not the same, which were 1.640 and 1.758 respectively.

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Why?" In this way, on the one hand, students' understanding of key and difficult points is deepened; on the other hand, the classroom atmosphere is activated, which is help for strengthening the interaction between teachers and students.

Post-classroom Thinking Questions

Post-classroom thinking questions are the continuation and expansion of classroom teaching. Its main purpose is to guide students to further study relevant teaching contents, apply what they have learned to solve practical problems, and cultivate students' scientific spirit and courage them to explore new knowledge. When designing post-classroom thinking questions, we paid attention to the aspects of "frontier", "integrating", "exploring" and "military".

Frontier. "Frontier" means that the latest research in related fields should be introduced into post-classroom thinking questions, helping to expand students' field of view. For example, in the section of "Diffraction of circular holes and resolution of optical imaging instruments", in order to deepen students' understanding of the resolution of imaging instruments and to understand the cutting-edge dynamics of microscopic imaging, we design a question: "What is the working principle of the super-resolution fluorescence microscopy, which is the 2014 Nobel Prize in Chemistry? Does it break the physical limits of diffraction?" Driving students to investigate and understand new microscopy techniques and compare them with traditional optical microscopes introduced in class. For another example, in the section of "Light dispersion of Medium", in order to deepen students' understanding of the concept of group speed, we set up a question: "Can group velocity be faster than the speed of light? What is slow light material? What is negative refractive index material?" They are the most cutting-edge research topics currently, and there are no determined answers for them. Although it is difficult for students, it has a positive effect on cultivating students' skepticism.

Integrating. "Integrating" means that the answer to a thinking question integrates two or more learned knowledge points, and it can exercise the ability of students to flexibly use the knowledge they have learned. For example, in the section of "Polarization of light", we design a thinking question: "Put a layer of scotch tape between two polarizer, then you will see the color change when you turn the polarizer near your eyes. Do you know the mystery of it?" It combines the knowledge points of polarization optics and dispersion optics, and only a thorough understanding of these points can give the correct answer. For another example, in the section of "Light dispersion of Medium", we give a question: "What is the difference between prism dispersion and grating dispersion?" It combines the knowledge points of geometric optics and physical optics, which will deepen students' understanding of the concept of dispersion.

Exploring. "Exploring" means that thinking questions should involve some new fields, new phenomena, no standard answers, and are obviously exploratory. For example, in the section of "Light dispersion of Medium", combining with our own research work, we set up a question: "How to realize an all fiber-optic group velocity dispersion measurement system?" This is a frontier topic in fiber field. There are few references, and students need innovative thinking according to what they have learned in class, which is very helpful for cultivating students' exploration spirit and innovation abilities. For another example, in the section of "Light scattering by medium ", we set up a question: "Do you know the mystery of Buddha Light?" There are no unified answers to the generation of Buddha Light, which involves scattering, dispersion, interference, diffraction, and other physical processes. Students can make bold thinking, which is very useful for cultivating their divergent thinking.

Military. "Military" refers to the military application of the thinking questions, which is in line with the teaching objectives of the military optoelectronic professional curriculum and students. For example, in the section of "Polarization of light", we give a question: "What applications does the principle of reflection-related polarization have in military fields?" Through a large amount of reading related literature, students can broadly understand the detection and identification technologies of military targets based on polarization. For another example, in the section of "Light dispersion of medium", we give a question: "What is the role of dispersion in supercontinuum
generation in fibers? What are the applications of supercontinuum lasers in the military? It can help students not only forming a systematic grasp of classroom teaching contents, but also understanding the newest military equipments, which is very beneficial to their future work.

Conclusions
Thinking questions are the supplement and extension of classroom teaching contents. It is an indispensable part of the teaching activities, playing an important role in deepening students' understanding of the difficult and key teaching contents, guiding students to explore the relevant unknown areas, and training students' abilities of applying the knowledge they have learned to solve practical problems. In the process of teaching Physical Optics, this paper has carried out positive thinking and exploration on the design of thinking questions, and carefully designed pre-classroom, classroom and after-classroom thinking questions according to different teaching contents and goals. It has played a very good role in improving teaching effects and students' qualities.

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References