ISSN 2522-6398 Vol. 4, Issue 10: 80-84, DOI: 10.25236/FER.2021.041016

Cultivating students'innovative ability in the college physics experiment

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Abstract: *College physics experiment plays an important role in students' practical ability, scientific quality and innovation capacity. Combined with actual teaching experience, the paper elaborates that college physics experiment cultivates students' innovative ability fundamentally from four aspects including experimental principle, experimental methods, experimental apparatus and experimental operation.*

Keywords: *college physics experiment; innovation; innovation ability*

1. Introduction

With the rapid development of science and technology, students who complete their higher education are required to have a solid foundation of natural science, excellent ability of scientific experiments, and great courage of innovation. In the era of knowledge-driven economy, innovation has increasingly shown its unique position and value. To some extent, innovation determines the comprehensive strength and competitiveness of a country or a nation. As the first practical course for those students who major in science and engineering area, college physics experiment is so important that it will never be replaced by other courses for exercising students' experimental skills, inspiring and nurturing students' scientific way of thinking and innovation ability, stimulating students' interests in scientific research, and improving students' scientific literacy. College physics experiment does not only contribute to the establishment of the physics concepts and principles, but also reflects the process of innovative development and innovation achievement of human society. College physics experiment has more than 100 years of history in the higher education and it plays an increasingly important role in cultivating students' creative ability. In modern higher education, it has become a powerful tool for cultivating students' innovative ability [1-8]. The innovative features of college physics experiment are stated as below by four aspects of experimental principle, experimental method, experimental apparatus and experimental operation.

2. Cultivating students' innovative ability in the college physics experiment

2.1 Experimental Principle and Students' Innovative Ability

Physics is an experimental academic subject. The laws of physics and its theory directly come from a large number of experimental facts which are observed, analyzed and summarized carefully. Whether a theory is correct or not completely depends on the test result by experiments, for example, from Galileo's experiments with rolling balls down inclined planes to Newton's three laws of motion, from Faraday's electromagnetic induction experiment to Maxwell's theory of electromagnetism. How to examine a theory with experiments? This is the problem that the experimental principle is supposed to work on. So, before a student does an experiment, he has to first understand the experimental principle and relevant ideas of experimental design. Only if he really grasps the principle of experiment, he could understand what this experiment is exactly going to do, and why he has to do like this. Then he could improve his ability of integrating theory with practice and the ability of innovative thinking. Taking the measurement of resistance by Wheatstone bridge for example, the experiment uses the principle of symmetry, which is particularly helpful for cultivating students' innovation ability. According to the electricity bridge balanced condition: $R_x = \frac{R_1}{R_2} R$ (Rx is the unknown resistance to be measured; R1 and R2 are resistances of proportional arm, R is the resistance of comparing arm). Therefore, there are two ways of adjusting the balance to measure Rx: one is selecting the proportional arm and adjusting R; the other is selecting R and adjusting the ratio of R1/R2. Since the measurement method is more than one way, student have to determine which method would be better with the minimum error? By analyzing, reasoning and calculating, students obtain the optimal conditions for measurement, that is, minimum measurement uncertainty could be reached when R1/R2=1. As a result, Rx=R. Some students might find that the Wheatstone bridge acts like a scale on which Rx and R are similar to the mass to be measured and its weight. In this way, the students' independent issue-analyzing and problem-solving skills could be improved. At the same time, their imaginative thinking had been naturally developed. Next, the teacher could guide students to ask, "How to reduce the experimental error caused by the unequal proportional arm in the experiment?" Students might reply, "According to the principle of symmetry, switch the place of Rx and R, and get the average value of Rx twice. This could reduce the experimental error of the unequal proportional arm." The teacher could ask the students further, "According to the principle of symmetry, do we possibly have any other way to reduce the systematic errors?" Some students might have another idea that considering the symmetry of galvanometer and power supply, keeping each bridge-arm resistance unchanged, exchanging the position of galvanometer and power supply, and taking the average value of Rx twice, would also reduce the error. By this experiment, not only had students been trained to be good at divergent thinking, but also students' interest in learning and enthusiasm for innovation would be greatly stimulated. For another example, in Newton rings and Michelson interferometer experiments, some students were confused by similar interference fringes because they do not understand the experimental principle. The teacher could respectively explain the principle of Newton rings and Michelson interferometer, and highlight that Newton rings is equal thickness interference and Michelson interferometer is equal inclination interference. Then the students can understood the same and differences better between Newton rings interference phenomena and Michelson interferometer phenomenon, and deepen their understanding of equal thickness interference and equal inclination interference. Thus the students could reinforce the concept of applying their knowledge, increase their awareness of combining theory with practice, and cultivate their sense of innovation.

2.2 Experimental Methods and Students' Innovative Ability

The comprehensive scientific research method has already been established since the age of Galileo, which is characterized by processes of phenomenon observation, assumption making, mathematical and logical reasoning, experimental tests and theory formation. In the case of college physical experiment, the specific basic experimental methods include direct reading method, amplification method, balancing method, comparative method, variable conversion method, simulation method and interferometry [9]. Each of the seven approaches contains a certain physical model, a scientific method and other thinking training material. In our experimental class, we not only teach students the principles of physics and deduce the measurement process, but also extract the measurement method from the principle and explain it in detail. By doing this we make sure that students can fully understand this measurement, which helps with both their scientific literacy and their creative thinking ability. For example, in the experiment Using Stretching Method to Measure the Elastic Modulus of Metal Wire, we first derived the measurement formula of the elastic modulus, and then we focused on the measurement methods of small elongation of the wire under weight. With so many measurement methods for length, we can use many tools like meter rule, vernier caliper, micrometer, etc. for direct measurement in most cases. However, can we directly measure a slight elongation of the wire with magnitude as small as 10-4m? After deliberation, the students answered "no" since they were aware that it was technically impractical for those traditional tools to take the measurement. How to measure it? Here the teacher presented a new measurement method - optical amplification method. This is a method that uses the small length changes of wire under weight to drive the optical lever to turn a small angle, then the small change of angle is transformed through a telescope into the change of the telescope's reflected light rotation angle, and finally through the reflection of light this change of angle is transformed into the change of readings in the scale. Optical lever amplification method can accurately measure the small changes in the length of wire, and it has been widely used in such measurement techniques as photoelectric galvanometer meter and ballistic galvanometer, both of which use the principle of small angle changes to show the reading. When the students heard this, they felt very interested and wanted to learn more about the clever ideas and infinite wisdom of predecessors, which inspired them to explore and try new ideas. In another example with the experiment of measuring "The Electrostatic Field Distribution", the teacher first posed a question, "Can we measure the electric field distribution by directly placing the apparatus or the probe into the electrostatic field?" Students answered "no" after thinking, because that would make the original distribution of the

ISSN 2522-6398 Vol. 4, Issue 10: 80-84, DOI: 10.25236/FER.2021.041016

measured field distorted, leading to inaccurate measurement results. At this time, the teacher introduced a new experimental method - the simulation method. This method simulates the current field distribution of the electrostatic field to be tested, and uses the current field of the direct measurement to simulate the electrostatic field. In short, in the process of experiment, students often encounter difficulties on the choice of experimental methods, and this in turn requires them to broaden their ideas, and to try new experimental methods. This is especially true for science and engineering students, so that they can give full play to their innovative capacity, and develop into useful talents in their future career.

2.3 Experimental Apparatus and Students' Innovative Ability

In the college physics experiment, the measurement of basic physical quantities like length, mass, current, voltage is the most basic experiment, and the key in these experiments is to decide which experimental apparatus to use so as to yield the most accurate results. Therefore, in doing these experiments, we should not only tell the students how to take the measurement, how to read the scale, but also draw their attention to the ideas behind the design of the apparatus, so that they can understand its structure and measuring principle. Students are also expected to consider how to determine the accuracy of the apparatus, how to determine the level of its accuracy from measurement data, how many significant figures to use, and what relations exist between significant figures and accuracy level of the apparatus. Only when they are clear about these ideas, can the students operate the apparatus with ease. This is an important component in improving their overall quality and innovation capability. In the past years, some colleges and universities implemented the open experimental teaching method [10-12], in which teachers let students choose which experimental apparatus to use based on the experimental requirements in the open laboratory. Giving the students both time and room needed for independent thinking and learning, this method thus creates an environment conducive to the development of students with creativity. It has been welcomed by the students, and has achieved good teaching results. For example, when measuring length, there are four measuring tools to choose from meter rule, vernier caliper, screw micrometer and reading microscope. However, when it comes to a specific experiment such as measuring the slit width, students have to use the most appropriate one. This requires them to compare the measurement data from the four tools, probe into their different levels of accuracy in measuring the same physical quantity, and analyze the relationship between the measurement data bits and the level of accuracy of the measurement tools. After detailed comparison, the students finally chose the reading microscope. Through the training of this experiment, the students learned that reading microscope is a precision length measurement apparatus with an accuracy of 0.01mm, and became clear about its structure and micrometer principle. With this they will know how to improve its measurement accuracy, be aware that the measurement data are not merely measurement results, but contain large amount of other information relevant to the accuracy of the apparatus and the accuracy of measurement results, which could help them correctly measure and read. Taking the voltage measuring apparatus for another example, there are a range of tools available, such as DC analog voltmeter, oscilloscope, potentiometer, digital voltmeter. Before students can make decisions as to which one to use, they should have a clear idea about the design of each tool, its structure and working principle, as well as its specific features and advantages. The whole decision-making process involves deliberate thinking and careful comparison on the part of the students, which is definitely a very good practice on their hands-on ability, the ability to distinguish between right and wrong, and their creative thinking.

2.4 Experimental Operation and Students' Innovative Ability

To take physical measurement in physical experiments, the first steps often involve adjusting the apparatus, observing the target, making judgment, and then reading the scale. In this process, the experimenter's operating skills and judgment can make a great difference in the measurement data, leading to varying deviations and dispersions, thus affecting the reliability of the measuring results. Therefore, the key in experimenting is to cultivate and enhance students' experimental skills so that they can derive objective and accurate experiment results free of distractions from "illusions" or other interference of the experimental phenomenon, and ultimately solve certain problems. If they can do this through their own hard work with independent thinking and hands-on experience, they will certainly experience the thrill of innovation, which will turn into their motivation for further research, and there will be new creation and thrill, and thus the cycle can go on and on. Taking the Experiment of Solid Density for instance, the measurement of quality requires the use of the physical balance, which is not new to students as they had already used the apparatus in high school. However, in practice, many of their operations are not standardized, such as regulating the balance nut or adding/subtracting weight in the start state, causing the beam to fall so as to damage the apparatus. Therefore, teachers in classroom teaching should pay attention to the students' procedures, and correct them timely when there are wrong operations. In regulating the balance of the beam, for example, (1) first turn the brake knob to start the balance, then observe whether the beam is balanced or not by watching the pointer, and then stop; (2) adjust the balance nut according to the offset of the pointer in the dial, then restart the balance, and then observe again to see if the beam is balanced; (3) repeat the procedure till the beam becomes fully balanced. By following this standardized procedure students can make sure that the beam does not fall, thus avoiding damage to the apparatus. What's more, following the procedures also enables them to develop good study habits and scientific and serious attitudes, which, in the long run, are beneficial to their improved innovative ability. On some occasions in the experiment, after following the correct procedure, students still encounter the problem that the balance could not be balanced due to severe wear of the parts in the balance. Teachers then can take advantage of this opportunity to engage students to think over the question: how to make it balanced? With deliberate consideration, some students are able to offer a solution by first adding weight in the regulation of the balance, and then converting the quality in later calculations. With a sense of achievement derived from their own successful efforts, those students become more interested in learning, and meanwhile, their ability to think independently and practice innovatively is also enhanced. In the experiment of Using Screw Micrometer to Measure Length, we used to focus on students' measurement results, and specifically the number of significant figures of their data, rather than their procedures in the experiment. In fact, in the measuring process, many students' operations are not standard, resulting in lower accuracy of the measurement results or equipment wear. Therefore, teachers should shift the focus to students' experimenting processes. To do this, students should be told at the beginning that to take the measurement, they need to turn the ratchet at the end of the screw micrometer to move the measuring rod, and stop turning when hearing a "click" sound made by the sliding of the ratchet, and then read the scale. By doing this, they can not only ensure that the measurement condition each time is constant, but also protect the precision thread of the screw micrometer. Any other operation would cause error in the measurement due to unstable pressure of the measured object, and increase the wear of the measuring rod thread, thus reducing the accuracy of the apparatus. Students should also be told that they should record the zero value offset, that is, the systematic errors of the apparatus, before taking the measurement, and that they should know about the positive and negative values of the systematic errors in different situations, and know how to eliminate their influence to the experimental data. Knowledge about this will enable students to use the screw micrometer correctly, and thus more likely to obtain accurate measuring data. This not only improves their hands-on ability and experimental capabilities, but also helps nurture a sense of innovation in them while doing experiments.

3. Conclusion

As a basic practical course, college physics experiment is not only rich in content but also incomparable in educational value of cultivating students' innovative ability. Therefore, college physics experiment course plays more and more important role in the process of cultivating innovative talents.

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