Practice And Exploration of Designing and Research Physical Experiments

MA Shihong WANG Yu ZHAO Zaizhong SHEN Yuanhua
Central Lab for Physical Education, Department of Physics
Fudan University, Shanghai, 200433

Abstract: Compared with traditional physics-experiments used to measure some characters of matter or prove some laws, designing and research experiment is better for developing students' initiative and creativity. In this paper, we introduce designing and research experiment applied to junior and senior undergraduates respectively in Fudan University in recent years. And the teaching method and the initial results are also discussed.

Key Words: designing and research experiment; physics experiments

1. Introduction

Physics is a fundamental subject. The development of physics has changed and is changing the whole world. Physics is also an experimental science. From the very beginning, none of the developments and innovations of physics are not related with physical experiments. All the innovations of physics result from the source of physical experiments, and are tested by the experiments. In order to cultivate research and application talents with higher innovation abilities, it is necessary that the students be armed with the abilities to explore problems, to solve problems, and to apply acquired knowledge to practice. This is the very purpose of opening college experiments in university. So the education of physical experiments should be one of important links in cultivating students' innovation abilities.

However, for quite some time, the teaching mode of base physical experiment is unitary, the contents are obsolete and the teaching approaches are inflexible. The contents of experiments are basically the verifications and measurements, and lack of research contents designed by students. The inflexible, contents and means of experiments teaching undermine the students' activity and positivity. So it is difficult to inspire the interest and enthusiasm for independent thinking. Without the experience of obtaining success from failures, students are deprived of the chance to develop their individuality, which is not beneficial to the cultivation of innovative talents. So, compared with students in developed countries, our students are usually excellent in examinations but lack of practical abilities, let alone creativity and critical thinking.

To change the situation, we have undertaken various reforms in recent years. For example, the elective subject, integrated experiment, was offered for the juniors since 1995. This advanced, designing, research, and integrative experiment course at a thorough training on students' experimental ability. In the experiment, all by themselves, students consult literature, collect information, deduce relevant theories, decide the scheme, select the apparatus, carry out the operation and measurement, and finally, write the paper and defend it. Actually, this integrated experiment is a designing and research experiment in the early phase.

Based on this work, and funded by *Reform Projects of Higher Education in 21st Century,* we have done a series of work in researching and exploring the new designing, research physics experiments in the central lab. Corresponding textbooks have been published, which are different from traditional experiment textbooks in that there are no detailed approaches or principles of the experiments, but only suggested task and questions that students have to answer by consulting referential books before they can design and undertake the experiment. The task can be fulfilled only with careful research and repeated practice .The following are the introduction of this practices.

2. The first type of designing and research experiment — the combination of science and interest

"Interest is the best teacher". It is necessary that the juniors be interested in physics experiments before they can improve and innovate. So, the first type of experiments focuses on combining science and interest, inspiring enthusiasm and innovation. Students are allowed to select subjects, decide the contents and degrees, design the experiment devices, prepare the apparatus, decide the experiment steps, and complete the experiment by themselves. The physical principles of these experiments are mainly of high school level. So they are easy enough for the freshmen. Its purposes are to inspire the students' enthusiasm and activity in learning physics, researching and exploring the physics rules, and to enhance the personal feeling and experience of physical laws and the abilities of practicing and thinking, and to inspire the

innovations.

A good example is the "impact shot" experiment improved from the "pendulum shot" experiment of Harvard University. The Harvard's experiment is that: the pendulum ball and thread of single pendulum are agglutinated by adhesive tape. When the pendulum sways to the lowest point, the heating cord burns apart the adhesive tape. Thus the pendulum throws horizontally. The teacher puts a target paper and asks students to calculate the height of pendulum in order to hit the target center, and to verify it through experiment, and compare their scores the target center scores 10. They consider it the most interesting experiment for students. We like the arrangement of the experiment, but the content is too simple for Chinese students. Figure 1 illustrates the improved equipment: instead of leaving the pendulum sway horizontally at the lowest point, we arrange it to impact another ball at the lowest point. The impacted ball is thrown horizontally and shot the target. The mass and size of the impacted ball can be identical with or different from those of the pendulum. The variations enrich the experiment contents. It proves that the experiment is excellent. It includes energy conservation, momentum conservation, pendulum motion, horizontally throwing motion, elastic impact, inelastic collision, etc. Giving students a chance to learn and use physics, it inspires their activity and enthusiasm in the interesting "shot game". In the process of experiment, they have analyze some reasons of the difference between measured values and calculated values, such as the air friction, friction of the impacted ball, energy loss in impaction, etc. They also discuss the factors that are ignored in the theory lecture, analyzing their effect, designing experiments to evaluate their effects. For example, they measure the height to which the impacting ball can rise without impacting in order to evaluate the friction effect, or they use different level tables to compare the effect of friction. The interest leads to enthusiasm. It gives freshmen an experience of scientific research.

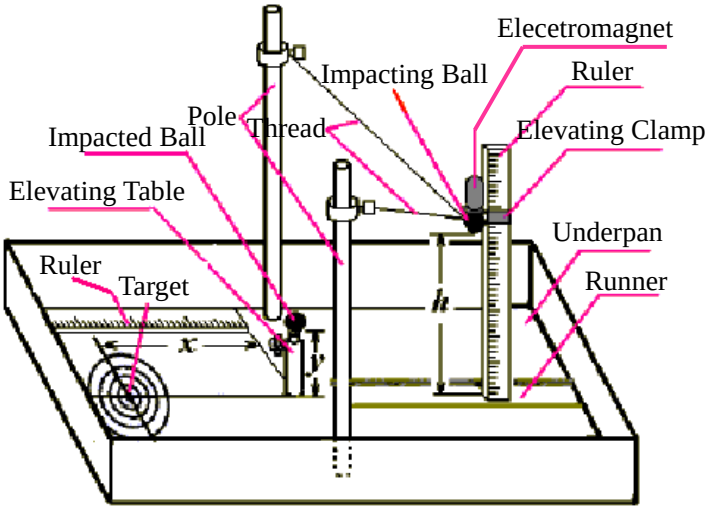

Figure 1 the Equipment of Impact Shot

It is appropriate to range the designing and research experiments to the general compulsory experiment teaching because the contents are mainly the same with those of the general experiments. Thus, every student has opportunity to do the experiments. Because the time for the general experiments teaching is limited, and the designing and research experiments time is variable, we allow students to do one experiment in two experiments' time or do two experiments in one experiment's time so that students have enough time at their disposal. It proves that this method is feasible and benefits all the students, because every student has his opportunity for training. However, it is not enough for the students who are particularly interested in physics. So, we offer an selective course "*Self-studying Physics Experiments*", for all students from various departments, which satisfied the needs of the students who have special interest in physics experiments so that they have a chance to do some interesting designing and research experiments in one semester with the result that their thinking is activated, their practical ability is improved and their initiative is inspired.

3. The second type of designing and research experiment — emphasizing on enhancement of the practical ability

For students majoring in science and technology, practical ability basically refers to researching ability. It includes the ability to consult literatures, design experiments according to special requires, discovery, analyze and solve the problems, summarize and induce problem, in practice, and compose papers and present orally papers in a international conference, etc. The cultivation of these abilities was ignored in general experiment educations. This is the weakness of our students. To enhance them, the designing and research experiments for sophomore and junior should be with research characteristic, and the students are asked to design, research, and accomplish a experiment task according to the requirements in 3-5 experiment times (9-15 hours). The students are given the right to consult materials not the experiment tests

and steps, and some instruments and elements (used or unused) not the sets of equipments in this experiment task. The principles of the experiments should be mastered by students in the college physics learning or can be mastered by a little additional knowledge. They start from consulting, planning, programming, and accomplish the experiment.

There are many of these experiments. We have listed 15 research subjects relating to Mechanics, Heat, Electromagnetism, Optics, etc. For instance, in the spectrum experiment, students were asked to study and compare the characteristics and application domains of different spectrum apparatus (prism and spectrum monochromator). Basing on this work, Zhou Liangcheng and Wang Yifan, the student of physics department 2000, initiatively asked a designing experiment using this monochromator and computer program to measure the objects' chromaticity. Figure 2 is the result of a pair of complementary color by computer calculus program. By a semester of hard work, they succeed. They presented a report in the Annual Meeting of *The Chinese Optical Society* in 2004, and published their modified paper in *Physics Experimentation*.

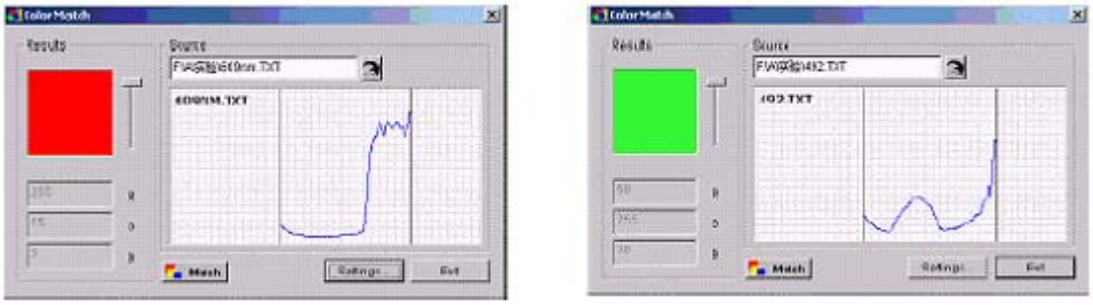

Fig. 2 The Result Color of Calculated – Red and Green (a pair of complementary color)

Finishing this experiment, the students were asked to summarize in paper and make an oral report. For them, it was the first "learned report" in their lives, they should be suggested to make reports using PowerPoint, including literal, images, pictures, videos, animations, etc. Reporting their own experiment is not only a training of writing and oral expression, but also experiences of widing their knowledge, communicating their experiences.

It is impossible to finish the experiment in one or two times of general experiment due to having many contents of designing and research experiments. We get round to 5—6 times designing and research experiments by cutting down general experiments measurement and verification experiment. We reduce the compulsory experiment from two semesters to one and a half semester. The exam was followed then, and the grade was sorted by the combination of general experiments and test. Besides the failures about 1/10 must redo the compulsory experiments, other 90% students, two students per team, selected a designing and research experiment and to do in the next half semester (the excellent students are asked to select them firstly). They should begin with consulting documentations, deciding the scheme, making program, and finishing the experiment. After the experiment, they were asked summer up in written and oral communicating. Every student submitted a paper-like experiment summarize and make report from all teams. The other students listened to the report and put questions. The questions putted by students are the one of criterion of grade considered by a teacher. The students have to listen seriously, think carefully, and learn to ask. Actually, this is an important learning way. Dr. Li Zhengdao has emphasized more than one times that: "knowledge ask man to question. But our students only learned answering not questioning. This is the important reason of leaking innovation." It is also an improvement that we take the questioning level as one of criterion of grade in our second type of designing and research experiment.

4. The third type of designing and research experiment — enhancing cultivation of synthesis and innovation ability.

On the base of the former two phases of learning, we ask definitely excellent students to (be on)"innovation". The aim of the third type of designing and research experiment is to "obtain innovation result". Students are asked to do the experiment in one semester, and make one or two research subjects. These subjects must be innovative. The contents and meaning of the subjects must be synthetical, which can evolve from the teachers' projects or were found by students in the experiments. We asked students to research, consult the materials, design, assemble, debug the experiment equipments, and finish the experiment.

For example, "Laser Tweezers" are higher technology of newly developed in the world. We found the Harvard University made a pair of cheap Laser Tweezers for undergraduate students' using in an paper of

Am. J. Phys, 1999. This set of Laser Tweezers cost them $6500. We thought we could do it cheaper than them. Sure enough, Chen Mingzhi, our student, made it in one semester and it cost only RMB 20,000. Furthermore, a lot of students have done experiments by using it. Figure 3 is schematic diagram of Laser Tweezers and photo of the equipment. And their paper was published in international conference on physics education in 2002.

This type of designing and research experiment was difficult to accomplish in short time in weeks, because of their wider subject and higher technology require. We have to open an independent elective subject, which was called as "Integrated Physics Experiment" or have been called "Simple Subject Experiment". For the accomplishment of the special wide research subjects, the students were given the key of laboratory and permitted to work in the laboratory any time. The students who have selected these experiments have strong ability of practice and active ability of thinking (their grades of all the subjects especially the experiments are above middle level). After having selected the subject by the team, which contains 2 students, the students present the experiment scheme only with the teacher's introductions of significance and background. The teacher only examines the preliminary scheme and guides the key steps. In the all education of experiment, the students were asked to apply creatively the knowledge and skill learned in college physics experiments and theory lectures to the researching experiment subject. They can

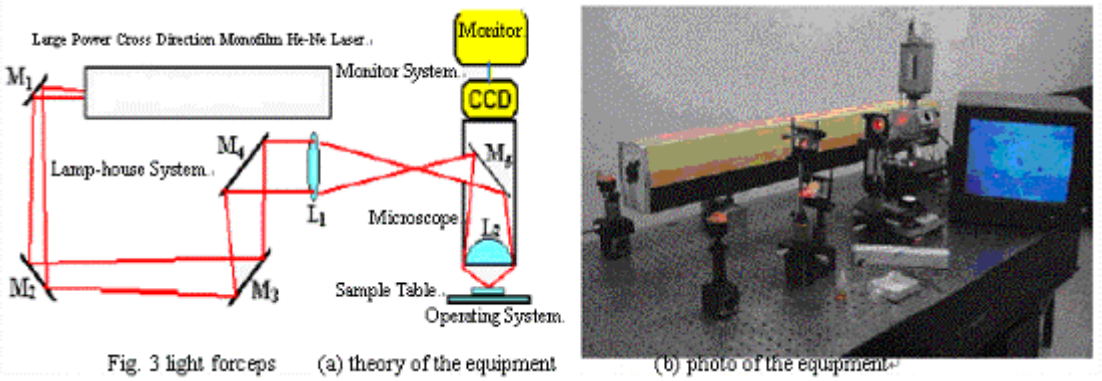

Fig. 3 light forceps (a) theory of the equipment (b) photo of the equipment

communicate and argue with teachers at any moment, and get enlightenment and help. But they cannot depend on teachers, and must do all the works by themselves. After the experiment, they write a paper, and answer and communicate the paper. There are some papers with innovations, and the excellent of them are published.

5. Self-evaluation of practice

We have made a survey of the students who take part in the designing and research experiment. They unanimously consider that the designing and research experiment give them more independence and have a chance to design the scheme and research the result of the experiment. Comparing the traditional measuring and validating experiment, the designing and research experiments are more contribute to cultivating their exploring spirit and innovation ability. They also said, "After the designing and research experiment, we feel its significant characteristic is it has no standard answer. All the things are opened, for example, selecting the equipments, planning the schemes, gaining the data, and discussing the results. These experiments are successful attempt of "miniaturization the scientific research, extending the students' experiments". It was good to cultivate the scientific spirit, scientific attitude, and will power. A lot of scientists were succeeding from the independent thinking in laboratory. Is the designing and research experiment a fertile soil of independent thinking? (Zhou Yajun, Department of Physics, 2000) "We can do what we want. We can consult materials, design experiments, and culture the spirit of cooperation. (Zhou Lihui, Department of Physics, 1999) …beside the students of physics department, the other students are welcome (for) the designing and research experiment. They said: "the most attracted is that it can make us to exert our practice ability" (Cao Ronggeng, Material Department), "It mages significant effect on our mastering the physics and high technology knowledge" (Ma Hong, Global Economics Department), "It gives us new enlightenment in the cultivation of innovation ability" (Zhou Wenyao, International Finance Department), "It is a good course of innovation education" (Pan Xinzu, Life Sciences School). … Though these experiments, the students' abilities of practice and innovation spirit have been improved very much. The tens of published papers have testified that the gains from these experiments are overwhelming comparing the general experiments!

6. Brief summary and practice reflection

In summary, compared to the traditional measuring and validating experiments, the contents and meaning of education of the designing and research experiment are different. Actually, the designing and research experiment is an important reform in the *Central Lab for Physics Education Experiment* in mostly universities in our country.

There are 35 experiments in the published textbook compiled by our experiment centre. These experiments fit the students from grade one to grade three, and need the time from 3 hours to one semester. The requirements of the experiments are from primarily designing experiment to research a new subject, including Mechanics, Acoustics, Heat, Electromagnetism, Optics, Modern physics, etc. Although these experiments were performed in Fudan University, and were proved to be feasible, there may be some difficulties in using the textbook for teachers of other universities. Because the reference books listed in the textbook are not easy to obtain, and in order to get better teaching effect, it is not enough only to use these reference books. So we also have compiled an electronic textbook as the *teacher's reference book of the designing and research physics experiment (CD Version)* for helping to open this course in other university. In this optical disc, we present the detailed and comprehensive answers to any questions in the experiment textbook. We also present hints and suggestions of the questions, which may be exist(ed) in the process of teaching (as teaching plan). These contents were collected from the experiences and feelings of the teachers' work in our experiment centre. Teachers can guide students in term of this book. But the students are not permitted to read this book, or else the all things are clear and there is no research or designing. But it is benefit to introduce some contents of experiments in the electronic-book, especially for the students with weak basic knowledge. What contents to introduce, how many contents to introduce are decided by the actual practice? We believe the set of textbooks can react as a pointer. Teachers of other schools can find and develop new designing and research experiments in terms of their different characters.

The designing and research experiment is not as steady as the measuring and validating experiment, which can (be) used for years. The designing and research experiment must be updated always. Some experiments have to be eliminated, because the elder students have done them for times and there are no contents for independently designing and researching. Adding new experiments is the key of maintaining the designing and research experiment's interest, advance, validity. So the experiment is a rolling development experiment, which be added new contents, eliminate olds, and improve ceaselessly every year. The experiment should reflect all kinds of research and education's results. For fitting the varied students and social requirements, the means of education should innovate unceasingly.

References

1. Ma Shihong, Shen Yuanhua, *Research and Development of the Designing and Research Experiments*, Reform-Innovation-Development (Vol. 1), (First Edition) Higher Education Press, pp. 260-263, August 2003.
2. Ma Shihong, Zhaozaizhong, Wang Yu, Shen Yuanhua, *Opening Elective Experiment Course, Cultivation Students' Innovation Ability*, **Physics Experimentation**, 22(3), 27-29, 2002
3. Shen Yuanhua, *Introduction of The Designing and Research Physics Experiment*, **Physics Experimentation**, 24(2), 33-37, 2004
4. Shen Yuanhua (editor in chief), Chen Yuanjie, Lu Shenlong, Ma Shihong, Ma Xiufang, Tong Peixiong, Le Yongkang, Zhao Tianxiang, Zhao Zaizhong, Zhou Ziping, Zhu Yongqiang, *Textbook of The Designing and Research Physics Experiments* (First Edition), Fudan University Press, 2004.
5. Shen Yuanhua (editor in chief), Chen Yuanjie, Lu Shenlong, Ma Shihong, Ma Xiufang, Tong Peixiong, Le Yongkang, Zhao Tianxiang, Zhao Zaizhong, Zhou Ziping, Zhu Yongqiang, *The Teachers' Reference Book of The Designing and Research Physics Experiments (CD Version)*, (First Edition), Fudan University Press, 2004.
6. Zhou Liangcheng, Wang Yifan, Ma Shihong, *Objects Chromaticity Simulation Using Software Program*, **Physics Experimentation**, 25(2), 21-24, 2005.2
7. Shen Yuanhua, Lu Shenlong, *Fundamental Physics Experiments* (First Edition), Higher Education Press, 2003.
8. Yan Zhichang, Ma Xiufang, *Physical Optics Experiment* (First Edition), Fudan University Press, 1993.