Research and Practice of Teaching Activity Integrating Scientific Research Methods into Material Thermodynamics

ZHANG Jun[1, a], PENG Na[2,b], WANG Meihan[1,c] and ZHAO Shilu[1,d]

[1]College of Mechanical Engineering, Shenyang University, Shenyang 110044,China)

[2]College of Environment Engineering, Shenyang University, Shenyang 110044,China

[a]email : zhjun88@126.com, [b]email: pengna418@163.com,

[c]email:2282642664@qq.com, [d]email: 437690893@qq.com

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Abstract. The classroom teaching of materials thermodynamics is proceeded based on the inherent connection and the evolution in materials thermodynamics knowledge system. The scientific research methods are introduced to the classroom teaching for the spread of scientific problems. In the progressive problems-oriented framework, the materials thermodynamics knowledge system is gradually established and the exploratory or inquiry-based teaching mode is constructed. In the levels of knowledge, method, thinking and the developing, the students' traditional learning process is transformed directly into innovation practice process, which results in re-building knowledge system. The progressive evolution of scientific problems plays a key role in the teaching mode which has been proved by the satisfactory implementation result. The students enjoy the creation process of new knowledge and improve innovation ability and scientific thinking level.

Introduction

In recent years, education strategy has been updated constantly. In higher education, more attention has been put on the student' personal quality as well as their innovation ability **[1-3]**. Many transformations have occurred such as from the cultivation of intelligence and the imparting knowledge to the cultivation of ability and emotion, from “knowledge goal” focusing on learning knowledge to “ability goal” focusing on learning methods, and also, from "develop the knowledge talented person" to “cultivate innovative talent”**[4-6]**. The cultivation of personal ability takes up more propertions than imparting knowledge to students in the current higher education.

From the epistemological perspective, it could be one of the most effective ways to cultivate innovation ability that the classroom teaching itself becomes the innovation process and the students' learning becomes the innovation practice. The development of scientific problems is the most direct and effective innovation process in classroom teaching. The scientific research methodsare vital to all of the development of scientific problems, the acquisition of scientific knowledge and the establishment of a scientific system. With the integration of scientific research methods, it becomes simpler and more effective for students to learn knowledge, put forward problems, analyze problems, solve problems, train thinking ways and develope innovation ability.

Materials thermodynamics is an important specialized foundation course linking general physics/higher mathematics with the specialized courses for the material majors. The course, in philosophy perspective, reflects the evolution from the universal law to specific application. From methodological point of view, the course gives an expression on how to propose scientific problems, how to make a scientific approximation, how to idealize experimental results, and also, how to use induction and deduction methods. As to the knowledge system, the course demonstrates how to make abstraction from complexity and how to apply the theory into the practice. Due to these typical characteristics, it is feasible to integrate scientific research methods with the teaching process of material thermodynamics course.

The purpose of the present research is to obtain a new classroom teaching way in which the learning and research, the inheritance and innovation can be well integrated so as to fundamentally avoid the separation between teaching and ability training, learning and innovation. The combination of learning and innovation not only promotes the formation of basic scientific literacy but also

provides a way to get a hold of the basic scientific research methods. At the same time, this new teaching way will help to propose and form new scientific methods and skills which reinforces the ability of creatively thinking. In return for the organization process of the innovation activity in the classroom teaching, the extensive course content and the integration of scientific thinking methods will enhance teaching level and ability of the teacher.

Research of Implementation Process

For the preparation of the course, firstly, the teacher must insight into the entire knowledge system and get a hold of the internal relations and development process of all the parts precisely, and then apply them to the classroom teaching. Following the framework of knowledge system, the teacher leads the students to develop the knowledge and to re-establish knowledge system by introducing the basic scientific research methods into classroom teaching activities.

Intrinsic link and evolution of material thermodynamics knowledge system Material thermodynamics describes the thermal phenomena and thermal movement and action by using scientific language, physical quantities. It reveals the relationships between physical quantities and the relationships between the changes of physical quantities.

Beginning with the equilibrium state and the concept of temperature, to the first law introducing internal energy which explains the nature of heat, to the thermal motion which is expressed by state parametric and their changes, to the reversible process and the irreversible process which show the directionality of thermal motion, to the second law of thermodynamics which is based on the principle of entropy increase and reveals maximum efficiency of the conversion from heat to work (mechanical energy), the thermodynamics fundamentals has been established accompanied by the expansion toward thermodynamics motion process and the application of Carnot theorem and Carnot cycle. Then, the complicated system is discussed by introducing a new state parametric, Gibbs free energy function. The proceeding direction of the thermal process can be determined by Gibbs free energy criterion. Based on the criterion, some of the scientific explanations and forecasts can be completed such as surface energy, saturated vapor pressure. Following those, the materials system is further divided in terms of constituent and phase. From the thermodynamic system of single constituent and single phase to the system of multiple constituents and multiple phases, the criterion is deduced for determining phase equilibrium / phase transformation of the complex materials system. Then, a new physical quantitive, chemical potential is proposed to reveal the nature of the phase transformation. In a spontaneous process, a constituent will transfer from the phase with relatively high chemical potential into the phase with relatively low chemical potential. Furthermore, the explanation and prediction of a set of phase changes can be completed, such as the formations of new stable phase and metastable phase, the precipitation of the second phase, the eutectoid decomposition, and the spinodal decomposition.

Integration of scientific research method In the whole teaching process, deductive reasoning method is applied throughout the knowledge system and can be used as a basic method to establish knowledge system. The methods to establish scientific concepts (physics quantities) are applied. Temperature is determined from qualitative to quantitative. Internal energy comes from reasonably reasoning of physical property. Entropy is proposed by mathematical differential method. Enthalpy and free energy come from the combination of the physical quantities. These are several basic ways to establish scientific concepts. The idealization method is widely used in the course, such as equilibrium state, reversible process, the ideal gas, the formation process model of solution, ideal solution and the others. As to knowledge structure, analogy method is early introduced to draw a analogy with Newtonian mechanics system. The analogy of the relationships between the three aspects of object, movement and action (force or energy) inspires the description of thermodynamic system, the thermal motion, the equilibrium state, state changes and heat action (heat energy). The importance of the scientific experiment and scientific observation methods is well shown in the course. Many typical scientific experiments, such as the constant pressure process, constant volume process, isothermal and adiabatic processes of the ideal gas, reveal the scientific laws. Maxwell relations offer another example. By conversing immeasurable quantity into measurable quantity,

scientific laws are verified. The scientific abstraction method helps to establish scientific concepts, such as thermodynamic system, internal energy, heat engine, and so on. These concepts reveal the common and the most essential characteristics. The axiomatic method is introduced to deduce Maxwell basic formula based on the first law with some original definitions of physical quantities through mathematical reasoning. This method is very useful to expand the relationships between physical quantities and their changes. The mathematics methods is widely used in the teaching activity. The new physical quantities established by mathematics methods have new features, such as enthalpy, free energy, Gibbs function. Moreover, mathematics methods are particularly suitable for revealing the quantitative relationship between the quantities or the quantities change, such as the establishment of G-T relationship and dP-dt relationship. The reasonable approximation and the equivalent substitution methods support the conversion of science into technology, such as Air-mixed cycle and Rankine cycle. The inverse problem method or reverse thinking method is involved in the course, such as from the heating cycle to the refrigeration cycle. This method not only provides new knowledge, but also causes the development of technology and innovation. The graphical method more intuitively and accurately reflects the relationship between the physical quantities, and even reveals some new laws or provides new explanations. The self-consistent method is applied and shows its importance in the derivation of Gibbs-Duhem equation. It reveals that the strict mathematical derivation must be consistent with definite physical meaning.

Implementation of the inquiry-based teaching mode Problem consciousness, as an internal driving force to think, is the foundation of the spirit of innovation and breakthrough. The most direct and effective innovation process mode in classroom teaching is expanding or developing scientific problems. Through progressive development of scientific problems, classroom teaching based on exploratory discussion is practiced successfully. Many goals are achieved, such as to obtain scientific knowledge, to establish scientific system, to enhance innovation ability and to master scientific thinking methods.

Inquiry-based classroom teaching mode characterized by progressive development of scientific problems includes the following aspects. First, the scientific problems is put forward, Second, the problem is progressively developed. Third, the interaction between teacher and students inspires thinking and discussions. Fourth, the integration and application of scientific methods and techniques in the whole teaching process. Fifth, the establishment of the knowledge system, to extract the dominating development line of the knowledge system. All the above five aspects have been applied throughout the classroom teaching until the knowledge system is eventually formed. Every time of class teaching, students experience the process, putting forward problems, analyzing problems, to search for a way to solve the problem and then to put forward a new problem. This training process greatly improves the thinking strength, prolongs thinking time, gradually forms scientific thinking habit and helps to master scientific research methods. Enjoying the results created by thinking labor, the students more easily get a hold of the developing context and internal relation of the knowledge system.

The teacher, as the organizer and guide of exploratory teaching activities, needs to do a lot of preparation ahead of time. The teacher should have the assurance of overall system and the dominate line, and also, design the progressive direction of the problems and the possible joints. The teacher must be equipped with sufficient scientific methods and skills and be good at asking questions (possibilities) and good at guiding the direction of the discussion. Following this way, each lesson will set up one or some ordered knowledge "modules" and will reveal the next development direction and problems. After a period of time, a summary of the foregoing knowledge, the main thread of development and the construct methods should be carried out. Finally, a knowledge system with complete structure and clear development lines is established.

Evaluation of Implementation Effect

At knowledge level Through the implementation of inquiry-based teaching mode, the students have achieved complete and clear understanding of the knowledge system and the development process of problems evolution. At the same time, the key and difficult joints connecting the preceding

and the following contents, the integration of knowledge points and the inherent connection of knowledge structure have been understood and mastered.

At method level In the implementation of inquiry-based teaching mode, the students get a well understanding of many of scientific methods, such as the questioning method, the methods developing knowledge, scientific abstract method, inductive and deductive methods, and the others. Then, they gradually learn to use these methods to deal with new problems and new knowledge. A considerable improvement of scientific literacy is achieved.

At thinking ability level The students mainly learn how to think about scientifically, that is, the content and the problem of thinking, the perspective and the way by which the thinking proceeds, the method and skill of thinking, the entry point of thinking, and so on. A deepened understanding of the formation and development of scientific knowledge system, the transformation of science to technology application and the promotion action of science on social progress has been achieved. The students have gradually formed the ability to acquire new knowledge by themselves. At the same time, they enhanced the self-motivation and learning interest, and also, strengthened the learning initiative and self-confidence.

At teacher-students interaction level In the implementation of inquiry-based teaching mode, the students converted learning ways from passive to active. That is, from passively listening to actively thinking, from mechanical memory to understanding of multiple perspectives, from accepting knowledge to creatively developing knowledge, from learning knowledge to enjoying the creation process of new knowledge. All of these changes lay a solid foundation for improving their innovative ability and scientific thinking level.

Summary

Inquiry-based classroom teaching mode is established at the bases of the plot line of course knowledge system, the thinking tool of scientific research methods and the way of progressively guiding process. The progressive evolution and expansion of scientific problems and the integration of scientific research methods are applied through the whole teaching. The inquiry-based teaching mode directly changes the students' learning into innovation practice and implements re-building the knowledge system. The present teaching mode can be applied to other natural science course.

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