122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #12261

Fishing with Broken Net: Predicament in Teaching Introductory Physics

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Abstract

The algebra based *Introductory Physics* course is offered to all students majoring in Chemistry, Biology, and Technology. There has been extensive research on teaching this course over the past five decades, and many people have investigated it from different aspects, such as the knowledge structure construction and procedural thinking in problem solving. From our experience in teaching this course, we find that there is another intrinsic issue that has attracted little attention.

Newtonian Mechanics is an excellent topic for students to learn how to solve problems with a systematic knowledge base. However, for many students, this topic is just a collection of equations. We believe that it is helpful to provide an integration process after teaching the individual chapters. In addition, with a complete concept map in mind, students can appreciate the elegant structure of the theory and analyze problems more effectively.

I. Introduction

Introductory Physics should be an easy course, and most instructors learned it in high school without much trouble. Therefore, it is often a big surprise when one teaches this course for the first time and finds that it is rather hard for most students. There are several challenges for students in our school—a non-selective regional university, such as poor background in mathematics, low motivation in learning this course, part-time job with long working hours, and ubiquitous distractions. However, even the students from Harvard also have trouble learning this course.[1] Thus we need to think about what instructors can do in improving the learning experience of the students.

As pointed out by Randall Knight,[2] many instructors consider the students as younger versions of themselves. Therefore, they just teach from the way they learned this subject in the past. However, we have to admit that we are the anomalies and not the norm, and our students often have challenges we may not have experienced. Fortunately, in the past half century, many instructors have developed various techniques in teaching this course more effectively.

It is interesting to find that atavism happens also in the understanding of physical phenomena, and Aristotle's ideas are well alive in students' minds. Many physics concepts and laws are based on well controlled experiment, such as in vacuum. On the other hand, Aristotelian theory is derived from everyday life experience, so it is accepted naturally in the 18+ years of students' life experience. Therefore, when the physics concepts and theories are introduced, conflicts arise in students' minds. The Aristotelian pre-concepts are often more powerful, so it takes considerable amount of effort to turn the table around. Lillian C. McDermott and the Physics Education Group developed a set of laboratory-based modules that offer a step-by-step introduction to physics, and through an in-depth study of a few fundamental topics, students can develop critical scientific reasoning skills.[3] In addition, David Sokoloff et. al. also developed a set of labs that help students to learn physics concepts very effectively.[4]

A large portion of the students taking algebra-based introductory physics courses are from Chemistry and Biology departments, where they are used to memorizing but are not as good at lengthy derivations. Therefore, a common practice of many students in problem solving is "equation shopping." At the beginning this approach works, however, as more and more equations are available, students are often at a loss on which one to use. In order to cultivate a systematic approach in problem solving, most textbooks show the detailed procedures, and templates are also developed as helpful guidance.[5]

II. Concept Map

One of the challenges in teaching introductory level courses is the huge knowledge gap between the instructor and the students. In addition, in the instructor's mind the knowledge is well organized, but the knowledge students acquired is fragmented.[6] Therefore, it is helpful to show the whole knowledge structure while covering the details piece by piece. Fig.1 below shows a concept map of Newtonian Mechanics.

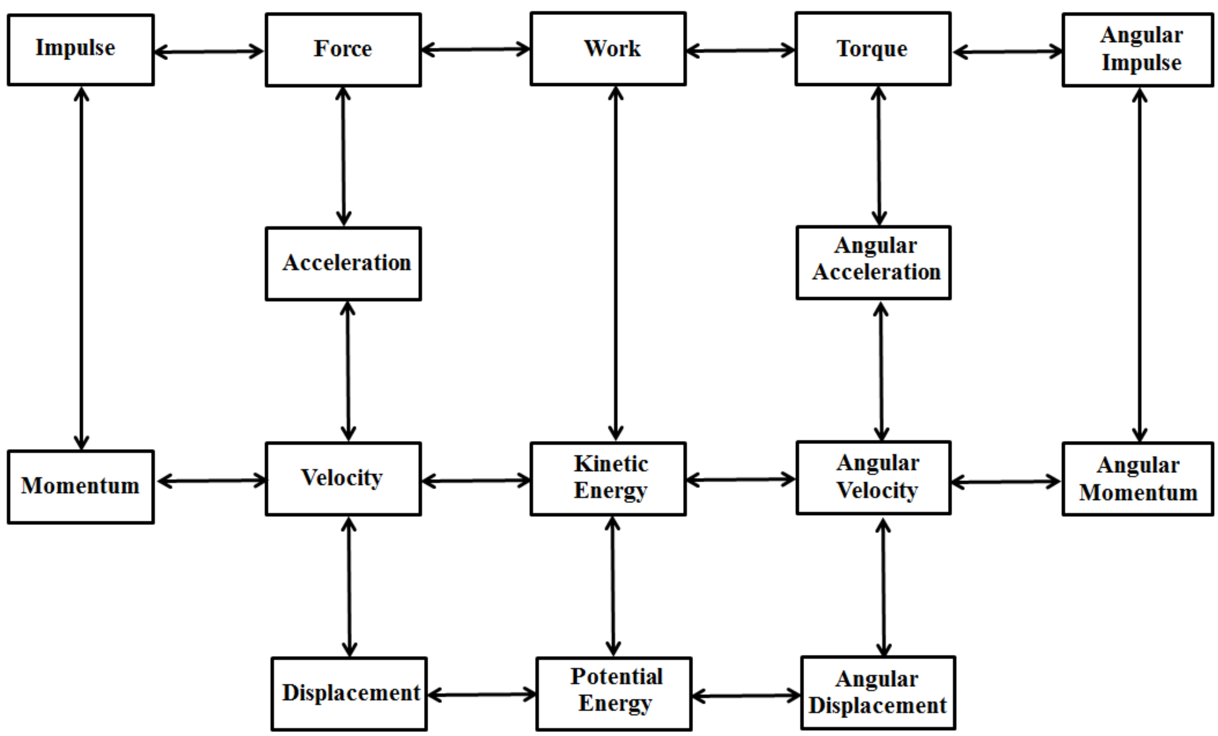

Fig. 1. Concept map for Newtonian mechanics.

At the beginning, the concepts of displacement, velocity, and acceleration were introduced in one dimensional situation. Basically all the problems in this part can be solved by means of three or four equations that relate these three concepts in different ways. Most students feel comfortable in working on these problems after some practice. However, after work-energy and impulse-momentum theorems were introduced in the middle of the semester, many students began to have trouble in identifying the correct equations in problem solving. This concept map was needed at this point, which shows the relations of concepts in the lateral direction. For example, velocity is not just related to displacement and acceleration, and it is also related to momentum and kinetic energy.

III. Concept Integration

After all the concepts shown in Fig.1 were introduced, we spent six lectures to review from a different perspective. In the textbooks these concepts were grouped vertically in silos and covered in different chapters, and thus students tend to have the same kind of knowledge structure. In the review at the end of the semester, we used a lateral approach. In this way, the problems were classified into five categories: problems in statics, problems with velocity but no acceleration (linear and angular), and problems with acceleration (linear and angular).

For example, projectile motion was originally introduced in the chapter on kinematics in two-dimensions. However, many problems in this area can be solved more easily by means of the impulse-momentum theorem (first column in Fig. 1) and mechanical energy conservation (third column in Fig. 1). In addition, students can gain a deeper understanding of these phenomena by analyzing it from different perspectives. Coin tossing is a familiar example: The rising and falling processes are symmetric in the speed of the coin, which is not well perceived for the students when it was analyzed with kinematics. However, from the point of view of mechanical energy conservation, this is obvious. Furthermore, the time of this process can be analyzed more readily by the impulse-momentum theorem, as the reversal of the velocity as the effect of the impulse of gravity.

The concept map shown in Fig.1 is symmetric between translation (on the left) and rotation (on the right). Therefore, after learning the laws and theorems in translation, students feel much easier to learning the counterparts in rotation, though it is less intuitive than translation. Furthermore, it is believed that this concept map can also help students to retain the knowledge long after they have learned this course. The details might fade away with time, but the framework will remain.

It is interesting to find that students often had trouble in solving problems in exams that are very similar to the ones they had worked out in homework assignments. This is not hard to understand, the homework problems are related to the knowledge just covered in the previous lecture, so students can find the right equations easily. This is not the case in exams, which cover a wide range of knowledge. In order to overcome this challenge, six review lectures were provided with a *horizontal* approach.

The first topic reviewed is on problems in statics, where both the sum of forces and the sum of torques varnish. The second topic reviewed related to problems with velocity, which is on the second level of the concept map shown in Fig.1. This topic has been discussed in several different chapters, such as kinematics, kinetic energy, and momentum. The third topic is on problems with acceleration and force, which is also related to the concepts of work and impulse on the top level of the concept map. The fourth topic is on problems related to circular motion, especially on centripetal acceleration and force. The fifth topic is on problems of rigid body dynamics, where the momentum of inertia plays an important role. The sixth topic is on problems with two-dimensional motion, such as projectiles.

In the textbook the concepts shown in Fig.1 are covered in the vertical direction, which can be considered as five threads. These review lectures forge horizontal connections across these threads and weaves them into a two dimensional net of concepts. When facing a problem in exams, students are expected to be able to locate the related key concept first, and then find the relationships in both vertical and horizontal directions. In this way, they can find the best way to solve the problems.

Although it is a good approach in theory, the implementation is not without problem. Because the review lectures were given at the end of the semester, the attendance dropped considerably. This indicates that students' effort was shifted to other courses, which emphasized more on the memory of facts, so they were more demanding in the weeks just before the final exams. In addition, without sufficient exercises on these new approaches, the review lectures were not very effective. Therefore, adjustment is needed in administering the review lectures so that the students can be more engaged.

V. Conclusion

In order to bridge the knowledge gap between novice students and experienced instructors, a concept map was created and handed out to students. After all these concepts had been covered in the lectures throughout the course, six review lectures were offered. If the conventional coverage of these concepts is considered as vertical approach, these review lectures follow a horizontal approach. In this way, the knowledge structure can be optimized into a net so that students can solve problems with different approaches.

Reference

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