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The Teaching and Learning of the Force Concept in Engineering Education

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Two ideas should be taken into consideration when planning a new course in mechanics: the students' preconceptions of the force concept and the analysis of the force concept in classical mechanics. By following this advice we tested engineering students' understanding of the force concept. The main results of the tests are: Students have the impetus conception of motion and they use the dominance principle in interactions. The analysis of the Newtonian force concept revealed two ideas which are contrary to both the students' ideas and the pre-Newtonian theory of motion. In Newtonian physics force is a relational concept which results from the interaction between bodies. Also the Newtonian idea that force is the reason for the changes of momentum is contrary to the students' ideas. Because of these empirical and theoretical facts the new course should be based on the concepts of interaction and momentum. The fourth chapter of this paper presents the implications for teaching.

1 CONSTRUCTIVISM

During the last decades the educational research has moved from behaviourism to constructivism. The basic idea of constructivism is that students construct and have to construct their knowledge through personal interaction with natural phenomena and through social interactions with adults and other students. Knowledge cannot be delivered. We can only give information from which the students construct their personal knowledge. Because of this new theory of learning there has been very intensive research worldwide on students' conceptions in many areas of physics, e.g. force, motion, light, energy. Research has revealed that students have constructed alternative concepts and they usually bring these "naive theories" to their dealings with the phenomena of physics.

The problem for teaching arises because these "naive theories" often tend to interfere with the students' ability to understand concepts presented in the classroom and this interference usually occurs regardless of how clearly the teachers present the concepts. The misconceptions often turn out to be deeply seated and difficult to dislodge, because individuals have spent time and energy constructing them. Students interpret our teaching with their own ideas and the result of a teaching period may be quite different from what we planned.

Because of the above mentioned reasons it is very important for the teachers to know the students' preconceptions. I believe that if engineering students understand physical concepts properly it is also easier for them to learn the more practical engineering subjects. In the following we report some results of two force concept tests with which I tried to find out how my pupils understand force and motion.

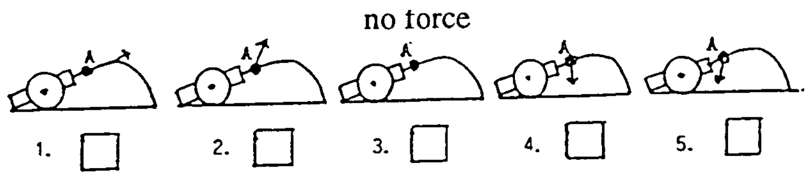
2 THE FORCE CONCEPT TESTS

2.1 THE FIRST FORCE TEST

2.1.1 METHOD AND SUBJECTS OF THE FIRST TEST

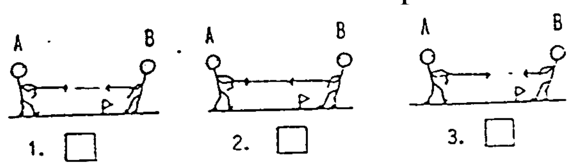
The first force concept test consisted of eight questions dealing with the qualitative understanding of the force concept and Newton's laws of motion. Questions were adopted from Watts and Zylbersztajn 1981. Some examples of the test questions are presented in Picture 1. In each question the students had to choose the appropriate answer and to explain why they had chosen that one. These explanations are the most important source of information about the students' ideas.

Question 1. A cannon ball is fired from the cannon. The arrows in the pictures are supposed to show the direction of the force on the cannon ball. Which picture do you think best shows the force on the ball as it is passing through point A



Explanation: ...

Question 2. This is a tug of war between two people. The flag shows the half way line. The person A is winning. Which of the following drawings do you think best shows what is happening? The size of arrows is supposed to show the size of the force that each person exerts on the other.



Explanation: ...

Picture 1. Examples of the questions of the first test.

The subjects for this study were engineering students in a Finnish institute of technology (Technische Fachhochschule) and physics students in a university. There were 28 first year engineering students and 26 second year students. The first year students had not studied mechanics in the technical institute. The number of physics students was 9 and they had studied physics for three years at the university.

2.1.2 RESULTS OF THE FIRST TEST

The results of the test questions considered in this lecture are shown in Tables 1 and 2. (The whole test is reported in Viiri (1992a).) The questions may seem to be very easy but as we notice from the results they are not. The questions reveal also many alternative conceptions. Engineering and physics students are able to calculate rather complicated exercises but it seems that in a way they do not understand what they are doing. The students have a "formula sickness": they try to find the first formula which fits the information given in the exercise. They do not usually look for the right formula which is in accordance with the physical situation.

Table 1. The percentages of answers in question 1.

Question 1	1	2	3	4	5
1st year engineering student	65	0	0	21	14
2nd year engineering student	12	0	8	58	22
3rd year physics student	56	0	0	44	0

Table 2. The percentages of answers in question 2.

Question 2	1	2	3
1st year engineering student	22	30	48
2nd year engineering student	67	17	16
3rd year physics student	44	12	44

From Table 1 we can see that about one third of the first year engineering students have understood the Newtonian force concept that force is the reason for the changes of motion. Two thirds of them think as Aristotle and medieval impetus scientists that force is in the direction of movement. The students' explanations are in accordance with this impetus-idea. Although the second year students have studied mechanics at the technical institute, still 12 % of them think that force is the reason for movement.

From Table 1 we can also see that more than half of the physics students think that force is in the direction of movement. They have not understood the Newtonian ideas although they have studied physics already in high school and they have had two mechanics courses at university.

From Table 2 we can see that only 22% of the first year engineering students have properly understood Newton's third law of motion. Most of them do not understand that the Newtonian force is related to the interactions the body has with its surroundings. One third of them think that if A is winning he has more force and this fact is shown in the picture with a longer force vector attached to A. This is one example of the so-called dominance-idea: the forces (action - reaction) are not equal but there is more force in the bigger or faster part of the interaction.

Students usually think that if the persons do not move any more (A has won) the forces are equal. But if B is still moving towards A the resultant force vector must be to the left. We can see that also this question reveals the idea that force must be in the direction of movement.

2.2 THE SECOND FORCE TEST

2.2.1 METHOD AND SUBJECTS OF THE SECOND TEST

The second test was translated from the force concept inventory made by Hestenes et al. (1992). The original test consisted of 29 questions from which we selected 14 for our test. The original test was made so that the questions would represent both the dimensions of the force concept and students' misconceptions of force. The reason for selecting only half of the original questions was mainly to concentrate on the interaction dimension of the force concept.

With this test we analysed engineering students' force concept after they had studied the mechanics course. The number of students was 40. In every question students had to choose the appropriate answer. Three examples of the test questions are shown in the Picture 2.

2.2.2 RESULTS OF THE SECOND TEST

The main results of the test are in accordance with the original test: students do not change their preconceptions very easily. Let us examine the results of the questions shown in Picture 2 more closely.

1. Imagine a head-on collision between a large truck and a small compact car. During the collision,

(A) the truck exerts a greater amount of force on the car than the car exerts on the truck.

(B) the car exerts a greater amount of force on the truck than the truck exerts on the car.

(C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.

(D) the truck exerts a force on the car but the car doesn't exert a force on the truck.

(E) the truck exerts the same amount of force on the car as the car exerts on the truck.

A large truck breaks down out on the road and receives a push back into town by a small compact car.

9. While the car, still pushing the truck, is speeding up to get up to cruising speed:

(A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.

(B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.

(C) the amount of force of the car pushing against the truck is greater than that of the truck pushing back against the car.

(D) the car's engine is running so it applies a force as it pushes against the truck but the truck's engine is not running so it can't push back against the car, the truck is pushed forward simply because it is in the way of the car.

(E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

10. After the person in the car, while pushing the truck, reaches the cruising speed at which he/she wishes to continue to travel at a constant speed:

(A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.

(B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.

(C) the amount of force of the car pushing against the truck is greater than that of the truck pushing back against the car.
(D) the car's engine is running so it applies a force as it pushes against the truck but the truck's engine is not running so it can't push back against the car, the truck is pushed forward simply because it is in the way of the car.
(E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

Picture 2. Examples of the questions of the second test.

In question 1 half of the students selected the alternative A which is in accordance with the dominance principle: greater mass implies greater force. The other fifty percent chose the right alternative E.

In question 9 again about fifty percent of the students answered correctly and the others chose the alternative C which reflects the dominance principle: the most active agent produces greater force. About half of these students had chosen the dominance alternative also in the first question. It is interesting to note that in the following question 10 about 80 % of the students chose the right alternative, 10 % chose the alternative C (the car exerts greater force) and 10 % the alternative E (no force). Although from the physicist's perspective the situations in the questions 9 and 10 are similar, students see them quite differently. In the first one the car is speeding and in the second situation it is moving steadily. So students think that in the first situation the car must exert more force because it is more active.

The results of both tests are in accordance with tests made in e.g. England, France and the USA on both engineering and physics students.

3 FORCE CONCEPT IN NEWTONIAN PHYSICS

Aristotelian and medieval physicists thought that bodies move because of their intrinsic properties. For instance, they thought that a stone falls to the earth because it has the intrinsic property 'heaviness'. This 'heaviness' had nothing to do with the gravitational interaction of modern physics. According to pre-Newtonian physics when a stone is thrown it receives something (impetus) with which it can fly trough the air. When the impetus has run out the stone starts to fall. The reason for motion and changes in motion inhere in the moving body.

Newton's method in Principia was to study the motions of bodies (kinematics) and from these motions investigate the forces (dynamics). His great new idea was to relate the motion of a body to its interactions with other bodies. If there are no changes in the motions there are no interactions and if the motion changes the moving body interacts with its surroundings. Force concept characterises the instantaneous strength of the interaction. In Newtonian physics force is a relational property, not an intrinsic property of a body.

In Newtonian mechanics the state of motion of a body is characterised with the concept of momentum. Because force is needed for the changes of motion (momentum) it is relevant to classify motion in the categories: no changes in motion and changes in motion.

4 IMPLICATIONS FOR TEACHING

If we base our instruction on the constructivist theory of learning we have to take the students initial ideas seriously. Since it has been shown in numerous tests worldwide that students do not change their initial "naive theories" by standard teaching we have to change our teaching methods.

One of the results of the force concept inventory made by Hestenes et al. (1992) was that we as teachers should concentrate on the impetus and dominance ideas. If students can overcome these two preconceptions they will understand also the other ideas of Newtonian mechanics. Also according to Licht and Thijs (1990), the dominance idea is the most difficult alternative idea. Because students have the impetus conception and it is almost like the momentum concept in physics, it might be worth while to start the mechanics course with a special concentration on the momentum concept. To overcome the dominance conception it might be valuable to concentrate on the interaction idea.

We should remember that it is not enough if we merely tell students the laws of motion. For instance, physicists are used to the categorisation of motion to non-accelerated motion and accelerated motion. But this categorisation is a completely new idea for students. In Aristotelian and students' physics it is relevant to classify motion in the categories: no motion and motion. This is because in Aristotelian physics force is needed for motion. If a body is not moving there is no need for force. Because of this fundamental difference it is relevant to study moving bodies' momentum and the changes in momentum in various situations. With these exercises students gradually receive the idea that momentum changes only in interactions.

The nature of students' preconcepts gives some implications for teaching. Firstly, we must concentrate on qualitative teaching methods, because the students' ideas are qualitative in nature. It seems that the students do not understand the force concept from purely calculating quantitative F=ma exercises. Secondly, we should use everyday situations, machines etc. in teaching, because the students have constructed their meanings in everyday situations. They do not relate the experiments made with sterile laboratory equipment to their information structure. Thirdly, teaching must be based on the students' personal activity so that they can construct their meanings themselves.

Teachers should produce a learning environment in which students can recognise and reflect on their ideas, realise that other people may hold other conflicting ideas, and evaluate the usefulness of these ideas alongside the teacher's scientific theories. When exposed to a range of learning activities, and given the opportunity to reflect, the pupils may then modify their ideas towards the intended learning outcome. (Needham, Hill 1987)

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