Qualitative knowledge in elementary mechanics

- a study of students in Linköping

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Abstract

Research focusing on concepts in Newtonian mechanics has been popular in the last twenty years. The reason for this is that it has been found that when students start a course in mechanics, many of them have beliefs that do not correspond with the concepts in Newton's theory, and to make students "unlearn" these beliefs can be very difficult.

In this essay a multiple-choice diagnostic test was used to examine the qualitative knowledge in elementary mechanics among students at the upper secondary school and at the university. The main purpose was to examine what concepts in classical mechanics are the most difficult ones for students to learn and to understand. But also other topics were examined; correlation between the physics grade and the result on the diagnostic test, difference between men and women, improvement on the diagnostic test after studying elementary mechanics and changes in the result on the diagnostic test in the last decade.

The results from the diagnostic test show that many students have difficulties to understand the concept of force. Many students believe that there has to exist a (net) force in the direction of motion, but they often use a mixture of this belief and the Newtonian force concept. The belief of "delayed forces" is also common; the students seem to believe that a force must not necessarily start (or stop) acting directly when it is applied (or removed).

In general, women have a lower result on the diagnostic test than men, also when comparing men and women who have the same grade from the physics A-course at the upper secondary school.

Physics education improves the result on the diagnostic test; the physics A-course at the upper secondary school seems to cause a clear improvement, but the improvement among men seems to be bigger than the improvement among women. A mechanics course at the university seems to cause only a small improvement on the diagnostic test.

No clear differences were found between the average results on the diagnostic test in these investigations and results from investigations in 1988 and 1989.

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Chapter 1

Introduction

1.1 Mechanics diagnostic test

In the last twenty years there has been a lot of research on physics education and especially research focusing on concepts in Newtonian mechanics. A lot of articles have been published that discuss conceptual knowledge in classical mechanics, and also how physics education can be improved with the help of results from investigations of students' conceptual knowledge.

In November 1985, Ibrahim Abou Halloun and David Hestenes published two articles in American Journal of Physics. The first of these two articles presents a mechanics diagnostic test, which can be used to examine and categorize students' conceptual knowledge in elementary mechanics (Halloun and Hestenes 1985a). This test has been used in my investigations, which will be presented in this essay. In the second article, students' *common sense concepts* are being categorized with the help from results of the mechanics diagnostic test from high school, college and university students (Halloun and Hestenes 1985b).

The mechanics diagnostic test constructed by Halloun and Hestenes will hereafter for short be referred to only as *the diagnostic test*.

1.2 Students' misconceptions

Depending on what is being discussed, different authors use different terms for when students' conceptions differ from the theories in, for example, Newton's classical mechanics. In this essay the term *misconception* will be used. A more detailed description (or perhaps definition) of misconceptions comes from Hammer 1996:

> the core idea is of *conceptions* that (i) are strongly held, stable cognitive structures; (ii) differ from expert conceptions; (iii) affect in a fundamental sense how students understand natural phenomena and scientific explanations; and (iv) must be overcome, avoided, or eliminated for students to achieve expert understanding. (p. 1318)

Research on science education has shown that before starting their physics education, students often have developed *preconceptions* ("common sense" concepts) in the areas that are about to be taught. It has also been found that very often these preconceptions differ from the concepts taught, and thereby they will be labeled as misconceptions (Ploetzner 1995 p. 248).

When trying to categorize students' misconceptions in elementary mechanics it is usual to compare the misconceptions with theories developed before Newton. Observed misconceptions seem to have most in common with the theory of impetus (Halloun and Hestenes 1985b and McCloskey 1983). The theory of impetus was developed in the 14th century and has some similarities with Aristotle's theory of motion. The most obvious difference between these theories and Newtonian mechanics is that they, unlike Newton's theory, claim that motion must have a cause. A statement that gives a description of the impetus theory comes from the French philosopher Jean Buridan, who most fully developed this theory:

> When a mover sets a body in motion, he implants into a certain impetus, that is, a certain force enabling the body to move in the direction in which the mover starts it, be it upward, downward, sideward or in a circle. (McCloskey 1983, p. 123)

It is important to note the difference between *misconception* and *lack of knowledge* (or *lack of concept*) (Hasan et al. 1999 p. 294). A person with a lack of knowledge in a specific field can more easily be taught the correct concept than a person with misconceptions, since the misconception first must be "unlearned". The person who holds the misconceptions must be convinced that these concepts cannot be used to describe and explain, for example, mechanical events. With the help from results on the diagnostic test together with interviews, Halloun and Hestenes (1985b pp. 1058-1059) noticed that to make students "unlearn" these misconceptions and to replace them with the correct concepts is not an easy task. That misconceptions are persistent and hard to overcome with traditional teaching methods[1] has also been noticed in other investigations (e.g. Clement 1982 and Hake 1998). It is important to note that this difficulty regarding conceptual understanding exists among all sorts of students. In his investigations, Peters (1982 p. 501) comes to the conclusion that "honor students, and by implication general physics students, often do *not* have firm grasp of the basic concepts."

1.3 Qualitative and quantitative physics knowledge

Physics education can (roughly) be divided in two parts, problem solving (the mathematical part of physics) and physics concepts. As pointed out by Ploetzner (1995), the physics literature and textbooks often focus on the quantitative, problem solving knowledge, and thereby assume that the qualitative, conceptual physics knowledge merely is a subset of the quantitative knowledge. But Ploetzner's investigations show that this relationship between the two types of knowledge is an incorrect description. Instead, qualitative and quantitative knowledge complement each other to build up the complete physics knowledge. Ploetzner also found that students make use of their conceptual knowledge in problem solving, and misconceptions lead to incorrect solutions or to no solutions at all. For successful problem solving, students therefore need a combination of the two types of knowledge.

[1] Several authors have been suggesting new methods of teaching to improve students' conceptual knowledge in a more dramatic way than with traditional teaching methods, e.g. Hake 1998, Halloun and Hestenes 1987 and Hein 1999.

The focus on quantitative knowledge also exists among students. As described by Hammer (1996 p. 1318), some students believe

> (1) that understanding in physics means being familiar with a collection of facts and formulas; (2) that the formalism of physics is only loosely associated with conceptual content or with what happens in the 'real world;' and (3) that learning physics means memorizing information and procedures supplied by the professor or textbook.

1.4 Physics education

Like any other type of education, physics education consists of many components that influence the quality of the education. The teacher with his or her knowledge and methods of teaching, the students who can be more or less motivated and with different pre-knowledge, and the textbooks with different ways of presenting the facts and theories are a few of these components.

Since it has been noticed that students who start a course in classical mechanics often have beliefs that do not correspond with the concepts in Newtonian mechanics, and that these beliefs are difficult to change, one should be aware of which types of preconceptions the students have, when teaching classical mechanics.

Unfortunately, the textbooks might cause misunderstandings among students in classical mechanics. Textbooks might even contain false statements (Edgar 1990), but perhaps more usual, formulations that could be refined to make it easier for students to understand (Marquit 1990). The language used both in textbooks and by teachers is a reason that students find classical mechanics difficult, since several concepts used in classical physics have "related, but potentially confusing meanings in everyday usage" (Williams 1999, p. 670). But many textbooks use the concepts in a way that might confuse the students even more. An investigation of textbooks shows that "the majority of our textbooks exhibit many […] linguistic problems" (Williams 1999, p. 672).

1.5 Purpose of the essay

The main purpose of this essay is to examine students' qualitative physics knowledge and what concepts in classical mechanics are the most difficult ones for students to learn and to understand. Those types of misconceptions, which are most common and most difficult for students to overcome during the years of physics education will also be examined. The investigations will focus on concepts like speed, acceleration, gravity and force. Most of the topics discussed and examined can be related to Newton's first and second laws. Newton's third law is also very important for the understanding in classical mechanics (Brown 1989 and Terry and Jones 1986), but students understanding of this law has not been examined in this essay.

The results from the diagnostic test will also be examined in relation to other things, such as the correlation between the result on the test and the grade in physics, and also whether men and women have different kinds of conceptual difficulties in elementary mechanics.

With this essay I will not evaluate the teacher's role in physics education. In my investigations I will only document and describe students' qualitative physics knowledge, and no suggestions will be made on how to improve students' understanding.

Chapter 2

Method

2.1 The diagnostic test

To examine the students' qualitative physics knowledge, the mechanics diagnostic test constructed by Halloun and Hestenes (1985a) has been used. It consists of 11 parts with a few questions in each part and a total of 36 questions. The questions have five alternative answers (except question five, which only has four), one correct answer and four (three) false statements. Thereby the chance level score on the diagnostic test is 7.3. All questions deal with concepts in classical mechanics, and no mathematical skills are needed.

The test was originally constructed for three different areas of use:

- Identifying students who might have difficulties in an upcoming physics course
- Evaluating the efficiency of a physics course in overcoming students' misconceptions
- A tool for identifying and classifying misconceptions

At first several versions of the test were created, which under a period of three years were given to around 1000 students who had to write the answers to the questions. Based on their answers, the multiple-choice questions were created. Thereafter the validity and reliability of the test was established in a couple of different ways, which resulted in the following conclusions:

- The students understand the questions and the alternative answers
- The students' answers reflect their stable beliefs
- The multiple-choice questions reflect the students' beliefs just as well as written answers
- The reliability is very high when comparing different, but comparable, groups

2.2 Changes and additions to the diagnostic test

To make sure the Swedish students would understand the questions and the alternative answers completely, the diagnostic test was translated into Swedish. To prevent the use of a technical language of physics, in some questions an imprecise language has been used in the original diagnostic test. In the translation I tried to keep this imprecise language, and not to use any other terms than those originally used. This was not an easy task and the translation could of course cause new problems in the formulation of the questions. But to prevent this from becoming a large error, the test was given to several students who would not take part in the upcoming investigations. Based on their comments some small changes were made to prevent possible misunderstandings. Of course, this small test cannot completely rule out the possibility that some students might misunderstand the questions or the alternative answers. The imprecise language might also mislead some students. One should keep this in mind when discussing the results and conclusions drawn from the diagnostic test, especially the translated version.

In the appendix to Halloun and Hestenes 1987 some corrections to the original diagnostic test are pointed out. The following changes have been made on the new version of the test used in my investigations.

Question 8: In diagram (a) the sides of the parabolic arc have been made smoother and not so flat. Diagram (c) was meant to spiral outward and transform into a parabolic trajectory to the left. This change has not been made due to difficulties in trying to create the intended diagram. But as pointed out by Halloun and Hestenes (1987 p. 461) few students have this belief, so this will not be a problem in the investigations.

Part 5: The description of the situation has been changed so that the tube is attached on the table.

Question 14: Diagram (a) has been made more clearly horizontal at the start of the path and diagram (b) has been changed to fall more sharply from point C. Thereby these two alternatives have become more easy to distinguish from each other.

Part 7: Labels A and B have been moved closer to the points they label.

Question 36: The misprint on the original test has been corrected.

Some questions on the diagnostic test deal with vertical movement (falling objects) with gravity as an important factor. In these questions, it is pointed out that one can ignore air resistance. But on the original diagnostic test, the air resistance is not mentioned in questions dealing with only horizontal movement. The air resistance is present also in these situations; the effect might be very small, but still there is an effect. Therefore the statement that one can ignore air resistance has been added to parts 5, 7 and 10.

As an addition to the multiple choice questions, the students taking the test were asked to give a motivation for their answers on one specific part of the test. The students could get one of three different parts, the first half of part 6 (questions 13-16), part 7 (questions 21-23) or part 9 (questions 26-29).

The students taking the test marked their answers on a special answering sheet, where they also had to give some information about their results on their completed physics and math courses. They were also asked to mark their gender. Apart from this information, the test was always performed anonymously.

The Swedish version of the diagnostic test with the changes and additions mentioned, together with the answering sheet can be found in Appendix A.

2.3 The test groups

My investigations focus on students in the upper secondary school[2] and at the university. The groups that took part in the test are listed in table 1. With these test groups I was able to examine students from their first year at the upper secondary school, when they haven’t studied any mechanics at all, all the way to the second year at the university, when they have finished the physics courses at the upper secondary school and one mechanics course at the university.

The first two groups, G0 and G1, are both in their first year at the upper secondary school, but the students in G0 attend the SP-programme (social science programme) and have thereby chosen to focus on languages, humanities and/or social science in their education at the upper secondary school, while the students in G1 attend the NV-programme (natural science programme) and will focus on mathematics and natural science. Groups G2 and G3 are also attending the NV-programme, but students in G2 are in their second year where they have started on the first course in physics, the A-course, while the students in G3 are in their third year where they have finished the physics A-course and are at the moment taking the physics B-course.

The groups at the university, U1e, U1 and U2, have completed the NV-programme at the upper secondary school or in some way complemented their original education so it becomes equivalent to the NV-programme.

Group U1e consists of students at the international part of I-programme (Ii) at the university, which consists of industrial engineering and management. These students are in their first year and have not studied any physics at the university.

Group U1 consists of students at the university who are studying to be teachers at different levels in natural science, and some also in mathematics. Most of them will be teachers in

Table 1. The test groups that took part in the investigations

	Group	**Programme**	**Year**	**Number of students**	**Physics education**
Upper secondary school	G0	SP	1	24	Will not study physics
	G1	NV	1	26	Have not, but will study physics
	G2	NV	2	18	Started on physics A-course
		NV	2	23	
	G3	NV	3	23	Completed physics A-course, started on physics B-course
		NV	3	24	
University	U1	Teacher	1	37	Introductory course in physics
	U1e	Ii	1	14	None at the university
	U2	Y	2	29	Completed mechanics course
			Total:	218	

2 In Swedish: ‘gymnasiet’

mathematics and natural science in the comprehensive school[3]; 16 will be teachers in mathematics and natural science at grades one to seven, 11 in mathematics and natural science at grades four to nine and four will be teachers at the upper secondary school (three in biology & chemistry and one in mathematics & physics), while six of the students in group U1 did not specify what they are studying. Since group U1 has not studied any physics at the university, except a small three weeks introductory course, and group G3 has completed the physics A-course at the upper secondary school, which contains classical mechanics, these two groups should essentially be comparable with regard to their knowledge in elementary mechanics. Therefore groups G3 and U1 will be joined to create a larger group when discussing results from the diagnostic test.

Group U2 consists of students at the Y-programme at the university, which consists of applied physics and electrical engineering. These students are in their second year when they have completed a course in mechanics, but not necessarily passed it.

The groups from the university, U1 and U2, consist of volunteers from the complete groups, which were about 120-140 students in each group. The groups from the upper secondary school on the other hand consist of complete classes. This could of course cause some students in these groups feeling unmotivated to take the test, while students in U1 and U2 should feel motivated since they volunteered to take the test. But I noticed few students in the groups from the upper secondary school that did not have the motivation to do well on the test. In contrary, several students asked if they could get the result or the correct answers after taking the test, so that they would know how well they had done.

2.4 Topics for investigation

In this chapter the purposes and goals with my investigations will be more specified than what was done in Chapter 1.5. The methods used for reaching these goals will also be described. These investigations are dealing with a variety of different aspects of students' knowledge in elementary mechanics. Each of the topics described below can be a starting point for a more thorough investigation. But the purpose of these investigations is to get some information on what can or should be more thoroughly examined. Different groups or part of groups will be included in the different parts of this investigation, group U1e, who did the English version of the diagnostic test, will only be included when comparing with old results.

2.4.1 Possible misconceptions

The main purpose of these investigations is to document and describe students' qualitative physics knowledge, with the focus on classical mechanics. This will be done by calculating the fraction with the correct answer on each question in each test group, and thereafter comparing the results from the different groups. With this analysis, possible misconceptions may be found by looking for questions that have a low fraction with the correct answer in *all* groups; this indicates a difficulty for students to understand the

[3] In Swedish: 'grundskolan'

concepts in the question, despite the different amount of physics education received in the test groups.

Whether it is a misconception or a lack of knowledge can of course not be determined, but nonetheless this method will find concepts that are difficult for students to understand, which will be sufficient for these investigations.[4]

2.4.2 Consistency in students' answers

Some investigations (e.g. Finegold and Gorsky 1991 and Gamble 1989) have shown that many students are not consistent when answering different but similar questions, which raises the question whether students hold so called *alternative frameworks*[5] or not, since a framework should consist of "interlocking concepts unifying more than one set of phenomena" (McClelland 1984 p. 1).

Instead, one big problem seems to be that students cannot grasp the generalization of the laws in mechanics. Gamble (1989 p. 81) noticed in his investigations that "many students who have been exposed to relevant physics tuition also exhibit little understanding or use of physics in non-stereotyped situations."

Halloun and Hestenes (1985b p. 1058) came to a similar conclusion, that "nearly every student used some mixture of concepts […] and appeared to be inconsistent in applying the same concept in different situations."

Many students seem to apply specific rules for specific situations, for example different force laws for objects at rest on surfaces, objects suspended from strings or objects in motion.

By looking at students' answers on questions dealing with equivalent situations, it will be examined whether they are consistent, either with Newtonian theory or some alternative theory. Some alternative frameworks are:

- *No* forces act on objects at rest
- If a body is moving, there is a (net) force acting on it in the direction of motion
- Constant motion requires a constant force
- Gravity is not a force, but a tendency for objects to fall towards the earth

2.4.3 How students use concepts in elementary mechanics

Thijs (1986 p. 18) found in his investigations among students "a lack of differentiation and articulation between various concepts of physics," for example between

- speed (velocity) and acceleration
- speed (velocity) and force
- force and energy, both potential and kinetic

[4] If one needs to distinguish misconceptions from lack of knowledge, the method with Certainty of Response Index, CRI, can be used (Hasan et al. 1999).

[5] *Alternative frameworks* and *misconceptions* are treated as different terms for the same thing.

Halloun and Hestenes (1985b p. 1058) found that “61 % [of the students] confused the concepts of position, speed and acceleration at least once.”

With the help from the answers on the extra question, where the students should motivate and explain their answers on a few questions on the diagnostic test, it will be possible to see how the students use concepts like speed, acceleration and force. It will thereby be examined whether they fully understand these concepts and if they use them in a correct manner.

2.4.4 Correlation between result on diagnostic test and grade in physics

Since textbooks often focus on quantitative, problem-solving knowledge (Ploetzner 1995 p. 249) one might assume that teachers thereby also focus on this type of knowledge when teaching physics. My own experiences as a student and when practicing as a teacher show that physics concepts are often discussed in class but seldom does any conceptual questions occur on the examinations. Therefore it might be interesting to examine the correlation between the result on the diagnostic test and the grade in physics, since this will show to what extent the grade could predict a student’s conceptual knowledge.

Since classical mechanics is a part of the A-course at the upper secondary school, the grade on this course will be used to examine the correlation, and the results from students in groups G3 and U1 will be used.

2.4.5 Difference between men and women

The results on the diagnostic test will also be used to examine if there is a difference between men and women regarding qualitative knowledge in elementary mechanics.

2.4.6 An attempt to predict the result on the diagnostic test

With the help from the analysis of the results from group G3U1 it will be attempted to predict the result from another group. The knowledge of possible differences between men and women together with a possible correlation between the grade from the physics A-course and the result on the diagnostic test will be used in this prediction.

2.4.7 Improvement on the diagnostic test due to physics education

The physics A-course at the upper secondary school and the mechanics course at the university are courses where elementary mechanics is being studied. The results on the diagnostic test in groups who have not completed the physics A-course will be compared to the results from groups who have finished this course to examine how much the physics A-course improves the result on the diagnostic test. In the same manner will it be examined how much the mechanics course at the university improves the result on the diagnostic test.

2.4.8 Changes in results on the diagnostic test in the last decade

The results on the diagnostic test from groups G3, U1 and U1e in these investigations will be compared to results from other university students in 1988 and 1989. Thereby it will be examined whether qualitative physics knowledge among students at the university has changed in the last decade. Since the old results come from groups who did the test in English and at home, group U1e also got to do the test in English and at home.

Chapter 3

Results and analysis

3.1 Possible misunderstandings among the students

When taking the test, the students were encouraged to ask about questions they didn't understand. By this I had a chance, if necessary, to clarify some formulations directly to the students who were asking. But this also serves as a pointer to which questions might consist of misleading formulations. The following questions occurred among the students.

Question 5: Some students didn't understand this question at all, and some were confused whether one could put point A "outside the earth's gravity".

Part 4 (questions 8 and 9): Despite the clear formulation that the rotation is "in a vertical plane in front of you", some students asked if the rotation was in a horizontal plane above the head. Others were confused by the figures (a) – (e) in question 8, since they were convinced that the rotation was in a horizontal plane.

Part 8 (questions 24 and 25): Some students, but not as many as on question 5 and part 4, asked whether there was any friction involved in this situation. My answer was always that there could be friction, but later I realized that the answer on question 25 depends on how big this frictional force is! If the frictional force is equal, but opposed, to the resultant force of F and F', the speed will remain constant, while a smaller frictional force would cause the puck to accelerate, which was the original thought.

Of course, only a minority of students asked about these questions, but there might have been many more students who for some reason didn't want to ask, but instead guessed. Some might also have been so certain in their misinterpretation of the question that they didn't even think about asking. Therefore the results from these questions will be handled with care.

3.2 General results

None of the test groups had any time pressure when taking the test, the students were free to use the time needed. Usually it took around 40-45 minutes to complete the test.

The test groups will hereafter only be referred to with their group name, where the groups G3 and U1 have been merged into one group as shown in table 2. The average total scores on the diagnostic test in the different groups are listed in table 3. Group U1e is not included since this group will not take part in any other investigations except when comparing with older results in Chapter 3.3.8. In table 3 one can see the expected increasing results in the groups. But the big difference between groups G0 and G1 is interesting, since these groups

Table 2. The group names that are being used in the investigations

Group name	Number of students	Group description[6]
G0	24	SP-programme, year 1
G1	26	NV-programme, year 1
G2	41	NV-programme, year 2
G3U1	84	NV-programme, year 3 and teacher-programme, year 1
U1e	14	Ii-programme, year 1
U2	29	Y-programme, year 2

have received the same amount of physics education. But this difference can be explained in a few different ways. Students in G0 might have felt less motivated to take the test since they have chosen not to study physics at the upper secondary school. Thereby they might have been guessing on many questions, which is supported by the fact that their average result is not far away from the chance level score of 7.3. Or perhaps the difference between these groups shows that the “right students” have chosen the NV-programme, the students who are interested in natural science and physics.

The difference between group G2 and group G3U1 is relatively small, two points. Since both groups have chosen to study physics at the upper secondary school, but group G3U1 have finished the physics A-course while group G2 has only just started it, one might have expected a larger difference. The difference between group G2 and group G3U1 will later be examined in more detail (see Chapter 3.3.7).

The students who had completed the physics A-course at the upper secondary school noted their grade on this course on the answering sheet. Several students in group U1 had grades according to the old numerical scale (1 to 5). These students are not included in investigations involving the physics grade. Also some students in both groups U1 and U2 did not give their grade, and are thereby also disregarded in these cases. But all students in U2 who gave their physics grade had grades according to the new scale. All students in group G3 gave their grade and all had grades according to the new scale.

The possible grades according to the new scale are; G for *Godkänd*, ’Pass’, VG for *Väl godkänd*, ‘Pass with distinction’ and MVG for *Mycket väl godkänd*, ‘Pass with special distinction’. The grades were also numerically translated in the same way as is being done when applying to universities; G=10, VG=15 and MVG=20. This gave the average grade

Table 3. Average result on the diagnostic test in the different test groups

	G0	G1	G2	G3U1	U2
Average result	10.2	15.8	19.2	21.2	30.1
Standard deviation	3.7	5.8	5.5	7.0	4.7

[6] For complete descriptions of the groups, see Chapter 2.3.

14.9 in group G3U1 and 19.5 in group U2. Since there is such a big difference between the average grades, these two groups *cannot* be treated as comparable. This difference in average grades might also explain the rather big difference in the average results on the diagnostic test (21.2 in G3U1 and 30.1 in U2), depending on whether there exists a correlation between the physics grade and the result on the diagnostic test. This will be further examined later on (see Chapter 3.3.3).

3.3 Topics for investigation – the results

The results from my investigations will be presented in the same order and classification as when the methods were presented in Chapter 2.4. In all results the possible error sources should always be kept in mind, for example the translation of the diagnostic test and the relatively small test groups. Due to the low result on the diagnostic test in group G0 and the high average physics grade in group U2, these two groups will not take part in some of the investigations.

3.3.1 Possible misconceptions

The fraction with the correct answer on each question in groups G1, G2 and G3U1 will be used to search for possible misconceptions.[7] The questions that have a low fraction with the correct answer in all three groups are noted. I here define "low fraction" as a fraction that is equal to or lower than 0.4 (±1 person). The questions that have a constant or decreasing fraction with the correct answer (±1 person) through the three groups are also noted. The result from this analysis together with the questions that fulfill both these two criteria, i.e., questions with a constant low fraction with the correct answer, is shown in table 4.

The questions with a constant low fraction with the correct answer are the questions most likely to reveal possible misconceptions. These questions will be examined in more detail. The rest of the questions that have a low fraction with the correct answer will thereafter also be examined, since there seems to be little improvement in these questions. The most popular wrong answer(s) on all these questions will be examined to search for misconceptions. A short description of the questions will be made before discussing the result, but I refer to Appendix A for the complete formulation of the questions.

Table 4. Analysis of fraction with the correct answer in groups G1, G2 and G3U1

Fraction with the correct answer	**Questions**
Equal to or lower than 0.4 (±1 person)	3, 7, 8, 9, 16, 19, 25, 32, 35, 36
Decreasing or constant (±1 person)	1, 2, 3, 5, 6, 8, 9, 16, 19, 22, 27
Constant low	3, 8, 9, 16, 19

[7] The fraction with the correct answer on every question in *all* groups can be found in Appendix B.

Questions 3 and 16

In question 3 a ball is thrown straight up in the air, while in question 16 a ball rolls of a horizontal surface a distance above the ground. The two questions are very similar since they both ask for the existing forces in situations where a ball is in a *free fall* situation, where gravity is the only acting force. Both questions have low constant fraction with the correct answer, which shows that many students have difficulties with the free fall situation, which can be alarming since the free fall is often used when discussing forces and movement in physics.

As shown in table 5 the most common wrong answer on question 3 is alternative (d), which claims that gravity is acting together with a decreasing upward force. This shows a belief that the force is directly correlated to the speed and the belief is close to the misconception that a constant speed demands a constant force in the direction of motion.

The most common wrong answers on question 16 include either a force in the direction of motion, alternative (e), or a horizontal force, alternative (d). But both these answers show a belief that there must be a (net) force in the direction of motion, which again directly relates forces to the speed.

Thereby these two questions both show that many students believe in a direct relation between force and speed, and that there must be a (net) force in the direction of motion, at least in a free fall situation.

Questions 8 and 9

As noted in Chapter 3.1 several students seem to have had problems in understanding part 4, which consists of questions 8 and 9. The misunderstanding has been whether the rotation occurs in a vertical or horizontal plane.

Besides the correct answer on question 8, alternative (a), the most popular answer is alternative (c). Certainly, if one thinks the rotation is in the horizontal plane, the most reasonable answer would be alternative (c). But of course it would be difficult to understand the other alternatives, especially alternative (b), if one thinks that the rotation is in a horizontal plane, which some students also have been confused about when taking the test.

Because of this misunderstanding among the students, the results on questions 8 and 9 will not be examined further.

Question 19

In this question a ball rolls of a horizontal surface at the same time another ball is dropped from the same height as the horizontal surface. The question is to decide which ball reaches the ground with the greatest speed.

In table 5 one can see that the most popular wrong answer on question 19 is alternative (c), which suggests that the two balls should have the same speed as they reach the ground. When taking the test, a couple of students asked whether this question asked about the "total" speed or the speed in the vertical direction. The result on question 19 shows that many students seem to have had this misunderstanding, since many answered alternative (c), which is the correct answer if one only take the speed in the vertical direction in account. Apparently many students have difficulty to understand the addition of two components of velocity, but one would need to ask the students why they answered as they did, to find out whether they for some reason just compared the speeds in the vertical direction but still are aware that one ball also has a speed in the horizontal direction, or if they actually think that the balls have the same speed when they reach the ground. This has not been done in these investigations.

Table 5. Most popular answers on chosen questions in all test groups (correct answer is marked with a star)

Question	Alternative answer	Fraction of students (%)					
		G0	G1	G2	G3U1	U2	Total
3	(a)*	8.3	34.6	26.8	32.1	93.1	37.3
	(d)	58.3	34.6	61.0	52.4	6.9	46.1
7	(b)	33.3	61.5	46.3	44.0	48.3	46.1
	(c)	41.7	19.2	31.7	17.9	6.9	22.1
	(e)*	12.5	19.2	19.5	32.1	44.8	27.5
16	(a)*	20.8	38.5	22.0	40.5	93.1	41.7
	(d)	20.8	15.4	41.5	36.9	3.4	28.4
	(e)	25.0	34.6	29.3	17.9	3.4	21.1
19	(a)*	33.3	42.3	34.1	41.7	86.2	45.6
	(c)	29.2	23.1	53.7	42.9	10.3	36.3
25	(a)	33.3	65.4	51.2	56.0	34.5	50.5
	(b)*	4.2	3.8	17.1	16.7	58.6	19.6
	(c)	12.5	15.4	17.1	21.4	3.4	16.2
30	(a)*	25.0	38.5	24.4	46.4	79.3	43.1
	(b)	37.5	15.4	26.8	33.3	10.3	27.0
	(c)	25.0	26.9	39.0	15.5	0.0	20.6
31	(a)*	16.7	50.0	70.7	76.2	96.6	67.6
	(b)	45.8	15.4	19.5	13.1	3.4	17.2
32	(a)*	4.2	19.2	22.0	40.5	72.4	34.3
	(b)	54.2	65.4	65.9	54.8	20.7	53.4
35	(c)	12.5	26.9	7.3	15.5	10.3	14.2
	(d)	25.0	42.3	58.5	42.9	37.9	43.1
	(e)*	29.2	26.9	31.7	34.5	51.7	34.8
36	(a)	33.3	50.0	56.1	38.1	13.8	39.2
	(b)*	29.2	23.1	29.3	36.9	72.4	37.7
	(c)	12.5	15.4	7.3	16.7	10.3	13.2

Question 7

In part 3 (questions 6 and 7) a block is released from the top of an incline, and one should name the variables that affect the speed that the block will have at the bottom of the incline. In question 7 the incline is frictionless and one can ignore the air resistance, while in question 6 one cannot disregard either the air resistance or the friction.

In all test groups more than 70 % of the students answered question 6 correctly (see Appendix B), while on question 7 the majority answered alternative (b) or (c), see table 5. This might show that the students have difficulties in understanding the abstract situation where neither air resistance nor friction exist. Both alternatives (b) and (c) suggest that the mass of the block will affect the speed the block will have at the bottom of the incline. The students either realize the similarity between the incline and free fall, but believe that the speed of falling objects depend on the mass of the object; or they do not realize this similarity but instead believe that the mass affect the speed on the incline. This result requires further investigations to reveal the true belief among the students, but the fact that as many as 68 % of all students think that the mass affects the speed on an incline is worrying, since the incline is often used as an example in mechanics!

Alternative (c) also includes the shape of the block as a factor, which shows that a number of students do not understand what friction is and what happens when a surface has no friction.

Question 25

As noted in Chapter 3.1 there is a risk of misunderstanding among the students on part 8 (questions 24 and 25). But most of the students seem to have understood the question as originally intended.

Most students answered question 24 correctly (see Appendix B), where one would choose a second force so that a plate moves in a specific direction. A correct answer results in a resultant force in this direction. Question 25 asks for the speed of the plate in this situation with the constant force. Most students answered alternative (a), which suggests that the speed will be constant. This clearly shows a belief that a constant force causes constant speed. So, once again it seems like many students have difficulty in understanding the concept of force, which also was noticed when examining the results on questions 3 and 16.

Question 32

Part 10 (questions 30, 31 and 32) consists of three differently shaped “bowls” in which a ball is released on one side. The questions are how high the ball can reach on the other side of each bowl (see figure 1).

A clear majority of all students answered correctly on question 31, while most students thought that the ball would not reach as high as the starting point, alternative (b), on question 32. This belief also occurred on question 30, but on this question there is also a

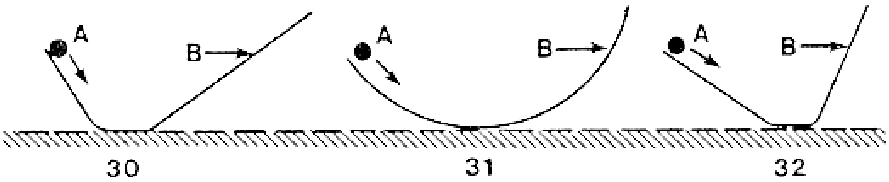


Figure 1. The "bowls" used in questions 30, 31 and 32. A ball is released on the left side of the bowl, and the questions are how high the ball can go on the other side in each bowl.

clear increase in alternative (c), which claims that the ball will reach higher than the starting point. These results show that many students seem to have difficulties in applying the energy principle, or understanding when to use the energy principle. Alternative (c) directly contradicts the energy principle, while regarding alternative (b), which claims that the ball will reach lower than the starting point, one would like to ask the students about where and how the loss of energy occurs, to find out if they are aware that they contradict the energy principle. This has not been done in these investigations.

Questions 35 and 36

In these questions a block is pulled along a given distance with a constant force on a horizontal, frictionless surface; the experiment is repeated a second time with doubled force. Question 35 asks to compare the speeds of the block at the end of the given distance in the two pulls, while question 36 asks to compare the times it takes for the block to reach the end of the distance.

The most common belief among the students is that there is symmetry; a double force causes a double speed in half the time, alternative (d) on question 35 and alternative (a) on question 36. This shows that many students either do not see the force as an acceleration, or they do see the force as an acceleration but do not completely understand the concept of acceleration, as the change of speed (velocity) per *time* unit.[8]

There is also a (smaller) group of students who believe that the doubled force will not make a difference, alternative (c) on both questions. These students clearly do not see the force as an acceleration, since they believe that a doubled force will not cause more increase of the speed.

[8] An investigation of 13 students understanding of acceleration resulted in the following conclusion: "When asked to define acceleration, many of the students produced the correct answer but failed to relate this to simple situations" (Jagger 1987, p. 25).

Table 6. Search for consistency in students' answers on questions 3, 12 and 16

Consistent belief	Fraction of students (%)					
	G0	**G1**	**G2**	**G3U1**	**U2**	**Total**
Gravity is a force	16.7	46.2	58.5	66.7	89.7	59.8
Gravity is not a force	0.0	0.0	0.0	0.0	0.0	0.0
Force needed to maintain motion	33.3	34.6	51.2	35.7	3.4	33.8
No force needed to maintain motion	0.0	26.9	14.6	25.0	79.3	27.9

3.3.2 Consistency in students' answers

Some questions on the diagnostic test treat similar situations, and these questions can be used to look for consistency in students' answers. Consistency of Newtonian beliefs will of course be examined, but a search for alternative frameworks will also be performed.

Gravity

By looking at the answers on questions 3, 12 and 16 it can be examined how many students consistently answer gravity as a force and also how many consistently show the belief that gravity is not a force. As shown in table 6, this analysis shows that none of the 204 students are consistent in this second belief, while 60 % of all students consistently label gravity as a force.

Force in the direction of motion?

Questions 3, 12 and 16 can also be used to examine whether the students believe that a force is needed to maintain motion. Table 6 shows that about 1/3 of all students consistently show this belief. This might be a problem in the following search for consistent beliefs, since so many students will include forces in the direction of motion, even when there does not exist such a force. This must be kept in mind in the following results in this chapter, especially from investigations on the questions where no net force exists.

Motion when no net force exists

Questions 10, 21 and 28 all ask for which path an object will follow in a situation where no net force exists. The analysis of the answers on these questions (see table 7) show that about 1/3 of all students consistently answer according to the Newtonian theory, while more than 40 % answer at least once that the object will not follow a straight line, which directly contradicts Newton's first law.

Questions 11, 13, 23, 29 and 34 all ask for the speed of an object in situations where no net force exists. In these questions, as well as in questions later examined when a net force

Table 7. Beliefs about motion (questions 10, 21 and 28) and speed (questions 11, 13, 23, 29 and 34) when no net force exists

Belief (C – consistent, O – at least once)	**Fraction of students (%)**					
	G0	**G1**	**G2**	**G3U1**	**U2**	**Total**
Correct straight-lined motion (C)	4.2	19.2	22.0	38.1	86.2	35.3
Not straight-line motion (O)	75.0	61.5	46.3	34.5	10.3	41.7
Constant speed (C)	0.0	7.7	31.7	39.3	89.7	36.3
Decreasing speed (C)	20.8	11.5	2.4	0.0	0.0	4.4
Decreasing speed (O)	91.7	92.3	61.0	56.0	10.3	59.3
Delayed forces (O)	83.3	61.5	36.6	28.6	0.0	36.8

exists, there are a couple of alternative answers that describe *delayed forces*. With this term I refer to alternative answers like "increasing for a while, and constant thereafter" in a situation where no net force exists. This shows a belief that a force must not necessarily stop (or start) acting directly when it is removed (or applied); thereby the effect of a force can be delayed both when it is applied and removed. The alternative answers that describe delayed forces are also accepted in the search for consistency. For example the alternative answer "increasing for a while, and constant thereafter" will be labeled as a belief that an object will move with constant speed, but also as a belief that there exists delayed forces.

The results in table 7 show that more than 1/3 of all students consistently show the belief that an object will move with constant speed when no net force exists, and just as many at least once show the belief of delayed forces.

A possible misconception when dealing with speed of objects when no net force exists can be that the object should slow down or stop when "no force exists to maintain the motion". But as seen in table 7 only 4 % of all students, and none of the students in groups G3U1 and U2 who have studied physics, consistently show this belief. But almost 60 % of all students, and more than half of the students in group G3U1, show this belief at least once.

Motion when a net force exists

Questions 15, 27, 33 and 35 all ask for the speed of an object when a net force exists. The delayed forces exist as alternative answers also on these questions and they are treated in

Table 8. Beliefs about speed when a net force exists (questions 15, 27, 33 and 35)

Belief (C – consistent, O – at least once)	**Fraction of students (%)**					
	G0	**G1**	**G2**	**G3U1**	**U2**	**Total**
Constant force ⇒ increasing speed (C)	8.3	23.1	22.0	33.3	72.4	32.4
Constant force ⇒ constant speed (C)	8.3	7.7	7.3	7.1	3.4	6.9
Delayed forces (O)	62.5	46.2	31.7	34.5	10.3	35.3

the same way as before. Table 8 shows the results from analysis of the answers on these questions. Almost 1/3 of all students consistently give answers that correspond with Newton's second law, $\mathbf{F}=m\cdot\mathbf{a}$, including answers with delayed forces. More than 1/3 of all students show at least once the belief of delayed forces on these questions. The possible misconception that a constant force gives a constant speed is consistently supported by 7 % of all students.

3.3.3 How students use concepts in elementary mechanics

On the extra question, the students should motivate and explain their answers on a few questions on the diagnostic test. The students were told to write a short explanation, so no detailed conclusions will be drawn in this part of investigation. The answers on the extra question were used to examine two things:

- If the students are able to explain why they answered as they did. Whether they have given the correct answer or not will not be taken into account, but if they can explain their answers.
- If the students use concepts in elementary mechanics in a correct way, or if they confuse some concepts.

The results will be formulated as general results for all students, and only obvious differences between test groups will be mentioned. Some examples of students' formulations can be found in Appendix C.

Many students are not able to explain their answers in a satisfactory way. Students who have answered the multiple choice question correctly more often give a clear explanation of their beliefs, while other students either do not give any explanation at all or just reformulate the alternative answer they chose on the multiple choice question. This does not support the theory of misconceptions, since students with misconceptions should be able to explain their beliefs more clearly. But one exception exists; students who answer the wrong alternative that there exists a force in the direction of motion are most of the time able to explain their answer. Their explanation is of course not valid, but this shows that their answer is grounded on stable beliefs, and can thereby be labeled misconception.

The fact that students cannot explain their answers might show that they do not fully understand what happens in the situation or what the causes are for these events. Instead they might be trying to compare the current situation with another situation where they know what will happen. Thereby they cannot explain the events since they have only learned by heart what will happen and they do not fully understand why.

The most common mix up of concepts is between speed and force. As noted several times before, many students believe that a force is needed in the direction of motion, and thereby they do not see the difference between speed and force. Sometimes formulations like "the speed affect the ball" exists in students' explanations, which shows a similarity between speed and force. But several students are inconsistent in their explanation, for example on part 6 where some students claim that there exists two forces on the ball that have rolled off a horizontal surface. A horizontal force, they claim, which is constant since the horizontal speed is constant, and the weight of the ball that causes the ball to accelerate in the vertical direction. Some students also wrote that when the ball is on the horizontal surface there exists no forces, and thereby the ball will move with constant speed.

Not many students used the term acceleration in their explanation, instead most used the speed to describe the motion and only a few students used energy to describe the situation.

3.3.4 Correlation between result on diagnostic test and grade in physics

The students in group G3U1 had all received a grade in the physics A-course at the upper secondary school when taking the diagnostic test. Some of them chose not to reveal their grade and some had grades according to the old numerical scale. These students will not be included in this part of the investigation. Thereby there are 72 students from group G3U1 who will be included in the investigations about the grade in physics, 21 have the grade G, 32 have the grade VG and 19 have the grade MVG.

In figure 2 the average result are shown as a function of the physics grade, where the grades have been numerically translated in the same manner as before; G=10, VG=15 and MVG=20. A linear regression analysis results in a correlation coefficient r=1.00 if it is done only with the average results. But if all test results are used the regression analysis gives a correlation coefficient r=0.55. This shows that it is much more difficult to predict one person's result on the diagnostic test from his or her physics grade compared to predicting a whole group's average result from the grades in the group. The physics A-course consists of more than conceptual mechanics, so it is not surprising that there is not a very good correlation between the result from one person and his or her grade in physics.

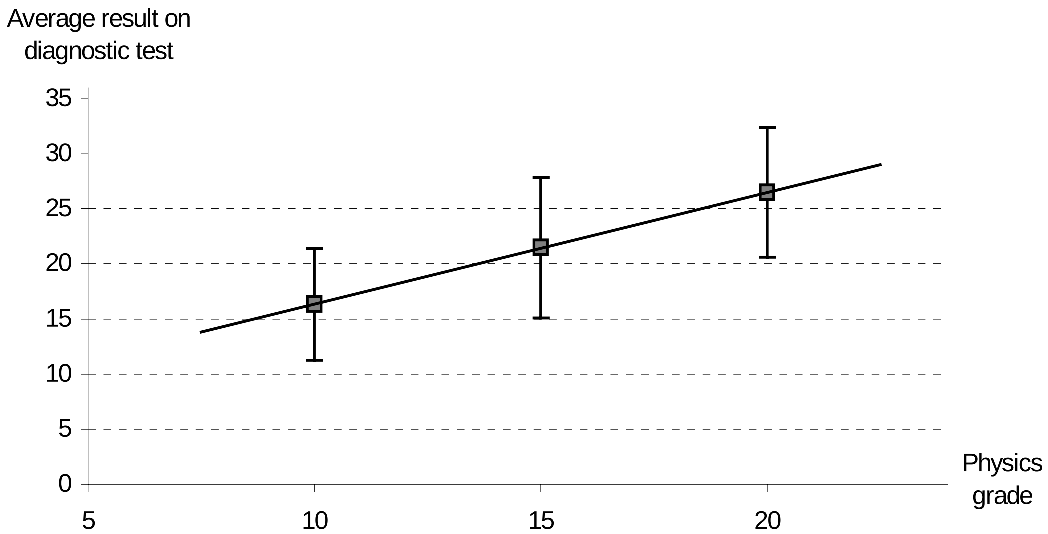


Figure 2. Average test result as a function of the physics grade (G=10, VG=15, MVG=20). The bars indicate the standard deviation, and the line indicates the result from a linear regression analysis.

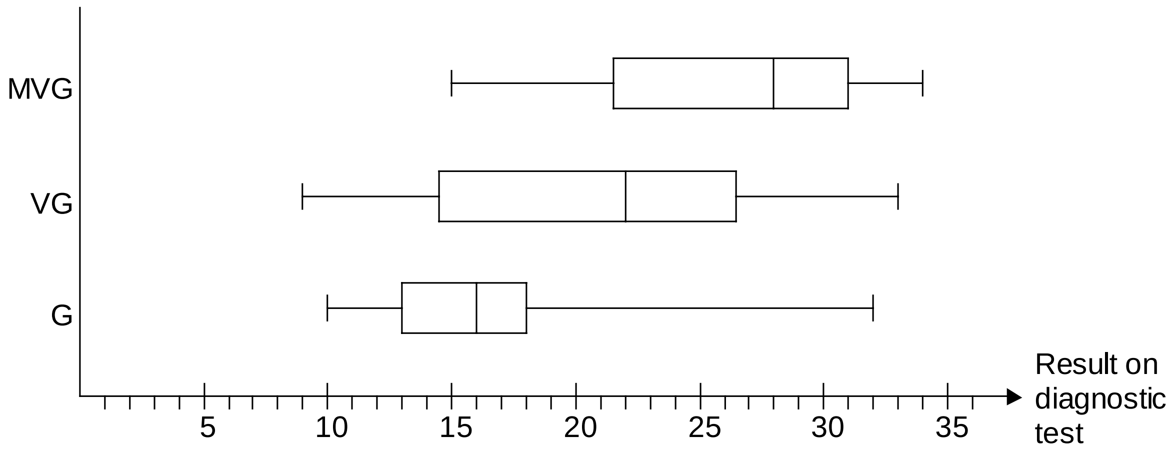


Figure 3. Results on the diagnostic test for students in group G3U1 with different grades from the physics A-course at the upper secondary school.

The standard deviation is of course a measurement of how spread out the results are in each group, but a box-plot[9] can be used to get a more detailed view of how spread out the results are, see figure 3. In the group with the grade G, the long line above the box shows that only a few results are very high. Disregarding the three best results, all students with the grade G have a result on the diagnostic test which is lower than 20. The students with the grade VG on the other hand are very evenly spread out with results from 9 to 33. Finally the students with the grade MVG seem not to be as spread out as the VG-group but more spread out than the G-group.

3.3.5 Difference between men and women

Not everyone marked their gender on the answering sheet, and those who didn't will not be included in this part of the investigation. Students who did not give their physics grade or who had grades according to the old numerical scale will also not be included. Since only two women in group U2 revealed their physics grade, this entire group will be excluded from this part of the investigation.

In table 9 one can see that women's average result on the diagnostic test is lower than the men's result in the same group. But group G3U1 also shows that women have a lower average grade in physics, and as earlier noted there exists a correlation between the grade in physics and the result on the diagnostic test. But a more detailed view of the students in group G3U1 divided in groups with respect to their grade (see figure 4), shows that women have a lower average result in each group.

[9] A box-plot shows, in order, the lowest result, the first (lower) quartile, the median, the third (upper) quartile and the highest result. Thereby 25 % of the results lie in each part of the box-plot.

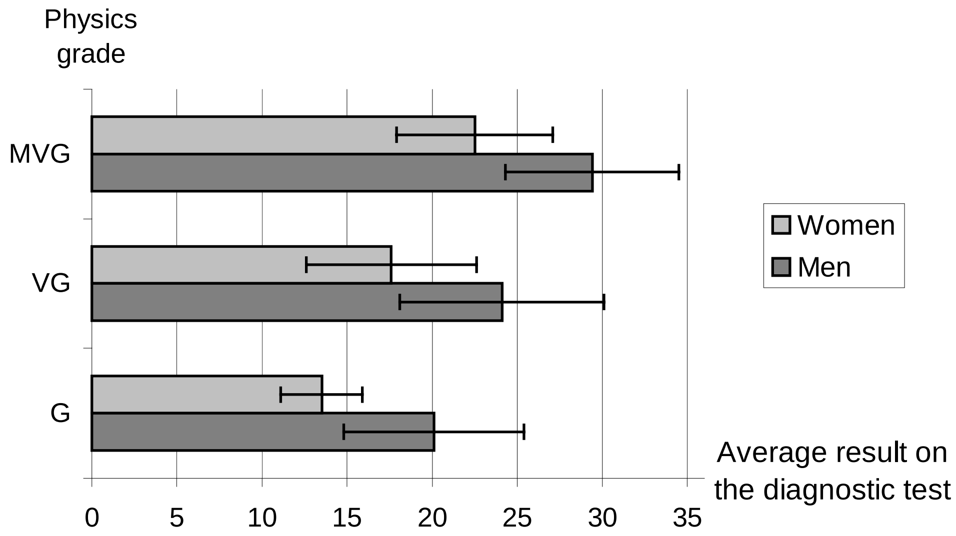


Figure 4. Average results on the diagnostic test for men and women in group G3U1 with different grades in the physics A-course at the upper secondary school. The bars indicate the standard deviation.

The differences between the women's average results and the men's are around 6.5 points in all groups. When assumed that the results come from a normal frequency distribution, statistical analysis show that the men's average results are higher than the women's with a certainty of more than 99 % in all groups.

To find a reason for this rather big difference between men and women is not possible in these investigations, since the grade in the physics A-course at the upper secondary school covers more than just conceptual mechanics; the quantitative physics knowledge is of course another area that should affect the physics grade. But it seems like women generally have more difficulties with qualitative physics than men. And perhaps men have more difficulties with quantitative physics than women. The last statement is of course just an assumption, which there is little evidence for in these investigations, but it is an assumption that would explain the differences shown in figure 4.

It is important to note that these results only deal with groups of students and average results in these groups!

Table 9. Average results on the diagnostic test for men and women

	Men				**Women**			
Group	**Number**	**Result**	**St. dev.**	**Grade**	**Number**	**Result**	**St. dev.**	**Grade**
G0	13	11.2	4.3	-	9	9.1	2.5	-
G1	16	19.1	4.7	-	9	10.6	2.9	-
G2	17	20.3	5.4	-	21	18.4	5.7	-
G3U1	39	24.7	6.4	15.3	33	17.3	5.5	14.4

Table 10. Attempt to predict the result on the diagnostic test

	Men		**Women**		**Total**	
	Result	**s.d.**	**Result**	**s.d.**	**Result**	**s.d.**
Actual	29.0	4.4	23.0	10.2	27.8	6.2
Prediction	27.8	6.4	18.7	5.3	26.0	7.0
Certainty of difference in results[10]	80 %		80 %		88 %	

3.3.6 An attempt to predict the result on the diagnostic test

A group of students from the I-programme (year 1) at the university did the test, but have not been included in these investigations so far. But they will now be used in an attempt to predict their results on the diagnostic test by looking at their grades from the physics A-course at the upper secondary school. The average results among men and women with different grades in group G3U1 (see figure 4) are used as the expected results when taking the test after completing the physics A-course. The group from the I-programme consists of 20 men and 5 women. Some of these students did the Swedish version of the test, but most of them did the English version, which can be an error source in this part of the investigation, since the students in group G3U1 did the Swedish version of the test.

The results in table 10 show that the prediction is quite good, at least among the men in the group. The prediction of the men’s result is only 1.2 points away from the actual result. The relatively small group of women could have caused the larger error (4.3 points) in the prediction of the their result.

3.3.7 Improvement on the diagnostic test due to physics education

Improvement after physics A-course at the upper secondary school

By comparing groups G2 and G3U1 one will find out how much the physics A-course at the upper secondary school influences the result on the diagnostic test. The average results among men and women with different grades in group G3U1 (see figure 4) are used as the expected results in the same manner as was done in Chapter 3.3.6. The grades from the physics A-course in group G2 can then be used to calculate the expected result from group G2 if they had done the test after completing the physics A-course. This will be compared to the actual result on the diagnostic test when they did the test at the beginning of the physics A-course.

Group G2 is made up of two classes (here named G2a and G2b), and due to some unexpected results, they will be treated separately in this part of the investigation.

[10] Using a t-test, where assumed that the results come from a normal frequency distribution.

Table 11. Expected change in result on diagnostic test in group G2 after physics A-course

	Group G2a			Group G2b		
	Men	**Women**	**Total**	**Men**	**Women**	**Total**
Result before physics A-course	19.0	15.9	17.7	21.4	19.6	20.3
Expected result after physics A-course	25.4	19.2	22.7	21.8	14.6	17.8
Change	6.4	3.3	5.0	0.4	-5.0	-2.5
	34 %	21 %	28 %	2 %	-26 %	-12 %

The results from group G2a (see table 11) show an expected increase in the result on the diagnostic test, but there is a clear difference between the change among men and the change among women. The women have an improvement of 21 % while the men have an improvement of 34 %.

The results from group G2b show something unexpected; there seems to be a decrease or an insignificant increase on the diagnostic test in this group! That the result would decrease with 26 % among women after completing the physics A-course is of course absurd. The source of this strange result has to be the way the expected result is calculated. But this method have shown to be quite accurate by examining the correlation between the grade from the physics A-course and the result on the diagnostic test (see Chapter 3.3.3), and also when trying to predict the result in a test group (see Chapter 3.3.6). It also seems like this method has worked when examining group G2a.

Another possibility is that since the expected result is based on the students' grade in the physics A-course, the group might deserve a higher grade than what they received! Or perhaps there can be other reasons for this strange result.

One error source in this analysis is that the grades come from all students in the test group, but all of them did not take part in the diagnostic test. Since this only involves a few students, it will probably not make any dramatic changes.

Improvement after mechanics course at the university

As noted earlier there is a big difference between the average test results in groups G3U1 and U2, and this difference was explained by the fact there is also a big difference in the average grades in these two groups. But now with knowledge of correlation between result on diagnostic test and physics grade, and the difference between men and women, this difference between groups G3U1 and U2 deserves to be examined in more detail to find out if there is an improvement on the diagnostic test after completing a mechanics course at the university.

Since group U2 consists of almost only men, two comparable groups are constructed by taking the men who have the grade MVG in both group G3U1 and group U2. 11 students in group G3U1 and 19 students in group U2 fulfill these criteria, and their average results on the diagnostic test are 29.4 in group G3U1 (with a standard deviation of 5.1) and 31.7 in group U2 (with a standard deviation of 3.7). The increase is 2.3 points (8 %). When assumed that the results come from a normal frequency distribution, statistical analysis show that the average result in group U2 is higher than the average result in group G3U1 with a certainty of 90 %.

When looking at the results from these two comparable groups, the difference is not as dramatic as noticed before. So the increase in the average result after completing a mechanics course at the university does not seem to be very big among these male students with top grades from the physics A-course at the upper secondary school. But on the other hand, their results are getting close to the maximum result of 36, so a more dramatic increase is perhaps not possible.

3.3.8 Changes in results on the diagnostic test in the last decade

The results from groups G3U1 and U1e will be compared with results from students who attended the I-programme (year 1) at the university in 1988 and 1989. If the groups are comparable cannot be determined, since too little information exists about the groups from 1988 and 1989, and one should therefore not draw any hasty conclusions from the results. For example, group U1e has the average grade 18.3 and group G3U1 has the average grade 14.9, while the average grades from the other groups are not known. The fact that group G3U1 did the Swedish version of the test while the old results come from groups who did the original English version makes these groups not directly comparable.

Table 12 shows the differences in how the test was performed in these groups together with the results. These results show no clear differences between any of the groups. So it seems like the students after completing the physics A-course at the upper secondary school have the same qualitative knowledge in elementary mechanics as they did about ten years ago.

Table 12. Old and new results on the diagnostic test

			Men		**Women**[11]		**Total**	
Group	**Location**	**Language**	**Result**	**s.d.**	**Result**	**s.d.**	**Result**	**s.d.**
I, 1988	At home	English	24.1	5.6	-	-	23.3	5.8
U1e	At home	English	27.8	5.4	-	-	26.9	5.9
Certainty of difference in results[12]			*74 %*				*96 %*	
I, 1989	At school	English	23.4	5.1	19.0	8.3	21.4	6.9
G3U1	At school	Swedish	24.7	6.4	17.3	5.5	21.2	7.0
Certainty of difference in results[12]			*79 %*		*72 %*		*55 %*	

[11] In some groups there were too few women to examine their results separately.
[12] Using a t-test, where assumed that the results come from a normal frequency distribution.

Chapter 4

Conclusions and outlook

4.1 Summary and conclusions

Some of the results from these investigations, regarding differences in the result on the diagnostic test between different groups, were expected. Groups who have received more physics education have better result on the diagnostic test, which shows that physics education improves the qualitative knowledge among students. Groups with a higher grade from the physics A-course at the upper secondary school also have a better result on the diagnostic test, which shows that the physics grade is a measurement of qualitative knowledge.

The most difficult thing in elementary mechanics seems to be to understand the concept of force; what a force is and how forces affect the motion of objects. Many students do not see force as acceleration but seem to regard a force as something needed to maintain motion; they thereby do not see a force as an interaction between objects, but probably as an intrinsic property of objects. The belief in *delayed forces* is also common; the students seem to believe that a force must not necessarily start (or stop) acting directly when it is applied (or removed).

Most students seem to hold a mixture of the Newtonian force concept and the “force-to-maintain-motion” belief. They often claim directly that there is a force in the direction of motion, but in another situation they might claim that when there is no force and no friction the object will move with constant speed. Sometimes they seem to have two different types of force concepts; one type of force that maintains motion and one force that can accelerate objects. Gravity is often seen as an accelerating force. The students thereby do not grasp the generalization of the theories and concepts in elementary mechanics.

Many students have difficulties when trying to explain why they answered as they did on the multiple-choice questions. Students who gave the wrong answer more frequently have this difficulty, which shows that these students most likely do not hold misconceptions, but have a lack of knowledge. But students who have the “force-to-maintain-motion” belief are often able to explain their beliefs, thereby it seems like this belief can be labeled as a common misconception.

There is quite a big difference between the average results from men and women, also when comparing men and women who have the same grade from the physics A-course at the upper secondary school. In these groups the women’s results are about 6.5 points lower than the men’s results.

The physics A-course at the upper secondary school seems to cause a clear improvement on the diagnostic test, but there is a rather big difference between men and women; the increase in men's average result is 34 % while the increase in women's average result is 21 %.

The mechanics course at the university does not seem to cause a clear improvement on the diagnostic test, at least not among men with top grades from the physics A-course. This was the only group of students who could be examined in these investigations. The increase in this group was 8 %.

No clear differences were found between the average results on the diagnostic test in these investigations and results from investigations in 1988 and 1989. Thereby students seem to have the same qualitative knowledge in classical mechanics as they did ten years ago.

4.2 Suggestions for further research

The results in these investigations show that many students who have completed the physics A-course at the upper secondary school still hold beliefs that do not correspond to Newtonian theory. Therefore one needs to examine if the education at the upper secondary school can be improved in some way or if the grade criteria is too low.

Good physics knowledge, both qualitative and quantitative, among teachers and future teachers is very important, since misconceptions among them might cause even worse misconceptions among their (future) pupils. Therefore, it should be important to examine the knowledge among both working teachers and future teachers, and thereby find out if it is necessary to change the courses in the teacher education or to offer working teachers further education.

The rather big difference between results on the diagnostic test among men and women serves to be further examined, to find the cause of this difference and also to investigate whether there is a difference also in quantitative physics knowledge.

The differences in improvement among men and women after the physics A-course serves to be further examined, to find out if the physics education at the upper secondary school manages to educate men better than women, and how this could be changed so that also women make a larger improvement.

The improvement among men with top grades from the physics A-course at the upper secondary school after taking a mechanics course at the university is quite small. But their results seem to be quite high already when starting the mechanics course, so one would need to examine students with a lower grade and also women, to see if the improvement is different among them.

The diagnostic test used in these investigations, originally published in Halloun and Hestenes 1985a, can of course be used in further investigations, but one should examine the questions that students seemed to misunderstand, and perhaps change or remove these.

Appendix A

Mechanics diagnostic test

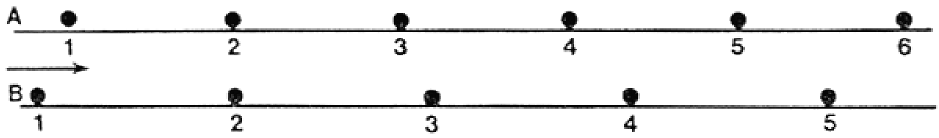
The diagnostic test used in these investigations was originally constructed by Halloun and Hestenes (1985a). Some changes have been made to the original test and a version translated into Swedish was also created (see Chapter 2.2). On the following pages one can find the Swedish version of the diagnostic test together with the answering sheet used in these investigations.

Diagnostiskt test inom mekanik

Testet består av 11 delar med ett antal frågor på varje del. Läs igenom alla svarsalternativ innan du besvarar frågan. **OBS!** Endast ett svarsalternativ per fråga får markeras.

Del 1 (1 fråga)

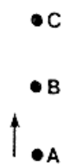
Två bollar, A och B, rör sig med konstant fart på olika plan. Siffrorna anger bollarnas positioner vid samma tidpunkt (tidpunkt 1, 2, 3, osv). Pilen anger riktningen av bollarnas rörelse. Bollarnas startpunkt visas ej i figuren.



(1) Har bollarna vid något tillfälle samma fart?

- (a) Ja, vid tidpunkt 2.
- (b) Ja, vid tidpunkt 5.
- (c) Ja, vid tidpunkt 6.
- (d) Ja, vid tidpunkt 2 och 6.
- (e) Nej.

Del 2 (4 frågor)



Figuren visar en boll som kastas vertikalt uppåt från punkt A. Bollen når högre än punkt C. Punkten B ligger mitt emellan A och C (dvs AB = BC). Luftmotståndet försummas.

(2) Vilken fart har bollen när den passerar punkt C jämfört med farten den har när den passerar punkt B?

- (a) Hälften så stor som farten i punkt B.
- (b) Mindre än farten i punkt B, men inte nödvändigtvis hälften så stor.
- (c) Samma fart som i punkt B.
- (d) Dubbelt så stor som farten i punkt B.
- (e) Större än farten i punkt B, men inte nödvändigtvis dubbelt så stor.

(3) Vilken kraft / vilka krafter verkar på bollen när den är på väg upp?

- (a) Dess tyngd, vertikalt nedåt.
- (b) En kraft vertikalt uppåt, som upprätthåller rörelsen.
- (c) Dess tyngd (vertikalt nedåt) och en konstant uppåtriktad kraft.
- (d) Dess tyngd (vertikalt nedåt) och en avtagande uppåtriktad kraft.
- (e) En uppåtriktad kraft, som till en början verkar ensam på bollen från punkt A till en högre punkt, varefter den nedåtriktade tyngdkraften börjar verka på bollen.

(4) Efter att bollen når sin högsta punkt ovanför C, vänder den och faller rakt ned. Hur stor är bollens fart när den på väg ner passerar punkt B, jämfört med dess fart när den passerade samma punkt på väg upp?

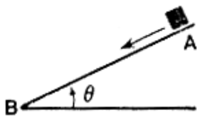
(a) Mindre än farten den hade på väg upp.
(b) Lika stor som farten den hade på väg upp.
(c) Dubbelt så stor som farten den hade på väg upp.
(d) Större än farten den hade på väg upp, men inte dubbelt så stor.
(e) Kan inte avgöras med den givna informationen.

(5) Om punkt A är tillräckligt högt upp, kommer då bollen att uppnå en viss fart som den sedan bevarar utan att farten ökar eller minskar? Luftmotståndet försummas fortfarande.

(a) Ja, på väg upp.
(b) Ja, på väg ner.
(c) Nej.
(d) Kan inte avgöras med den givna informationen.

Del 3 (2 frågor)

Figuren visar en kloss som släpps från toppen A på ett lutande plan med given längd AB och lutning (vinkel) θ.



(6) Vilken faktor / vilka faktorer påverkar farten som klossen kommer att ha när den når botten B av det lutande planet?

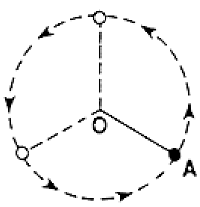
(a) Klossens form.
(b) Ytan på det lutande planet.
(c) Luftens densitet.
(d) Klossens form och luftens densitet.
(e) Klossens form, ytan på det lutande planet och luftens densitet.

(7) Antag att luftmotståndet försummas och att det lutande planet är friktionsfritt. Vilken faktor / vilka faktorer påverkar farten klossen kommer att ha när den når botten B av det lutande planet?

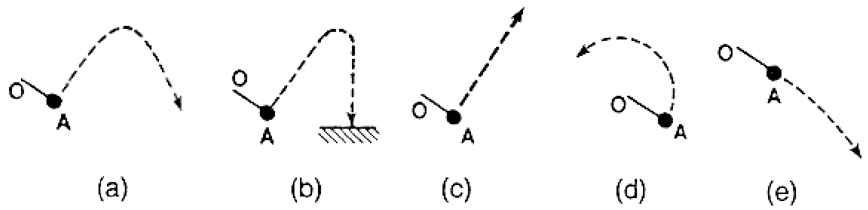
(a) Klossens form.
(b) Klossens massa.
(c) Klossens form och massa.
(d) Klossens densitet.
(e) Ingen av ovanstående.

Del 4 (2 frågor)

Figuren visar en boll i änden på ett snöre som du håller i handen vid punkten O och roterar med hög hastighet i vertikalplanet framför dig. Cirkeln visar bollens bana och linjerna från mitten O visar olika riktningar hos snöret när du roterar det i pilarnas riktning. När bollen når punkt A släpper du snöret. Luftmotstånd och all eventuell inverkan av snöret försummas.



(8) Vilken figur beskriver bollens rörelse efter att du släppt den i punkten A?



(9) Om du i uppgift 8 valde bana (a), (b) eller (d): Bollens fart längs den valda banan...

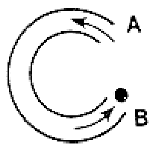
(a) är konstant.
(b) avtar från A till toppen av banan och ökar därefter på väg ner.
(c) avtar från A till toppen av banan, där farten blir noll och ökar därefter på väg ner.
(d) ökar en stund och är därefter konstant.
(e) ökar en stund, avtar sedan tills bollen når toppen av banan. Därefter ökar farten.

Om du i uppgift 8 valde bana (c) eller (e): Bollens fart längs den valda banan...

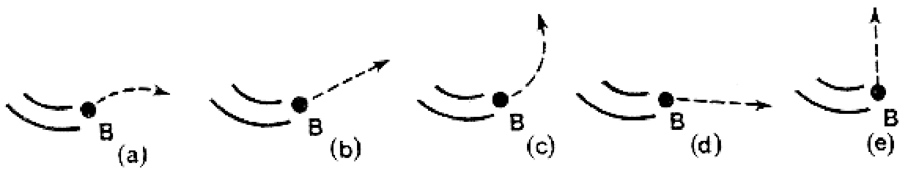
(a) är konstant.
(b) ökar hela tiden.
(c) minskar hela tiden.
(d) ökar en stund och är därefter konstant.
(e) minskar en stund och är därefter konstant.

Del 5 (3 frågor)

Bilden visar ett ihåligt, cirkulärt rör fastsatt på ett friktionsfritt horisontellt bord. Du tittar ner på bordet. En boll skjuts in i rörets ände A och kommer ut i andra änden B med hög hastighet. Luftmotståndet försummas.



(10) Vilken figur beskriver bollens rörelse på bordet, efter att den kommit ut ur röret?

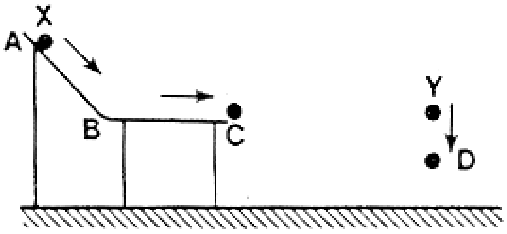


(11) Bollens fart längs den valda banan...
(a) är konstant.
(b) ökar hela tiden.
(c) minskar hela tiden.
(d) är konstant en stund och ökar därefter.
(e) är konstant en stund och minskar därefter.

(12) Vilken kraft / vilka krafter verkar på bollen längs den i uppgift 10 valda banan på bordet?
(a) Bollens tyngd, vertikalt nedåt.
(b) En kraft från bordet, vertikalt uppåt.
(c) En horisontell kraft, i rörelsens riktning.
(d) De två första krafterna, (a) och (b).
(e) Alla tre krafterna, (a), (b) och (c).

Del 6 (8 frågor)

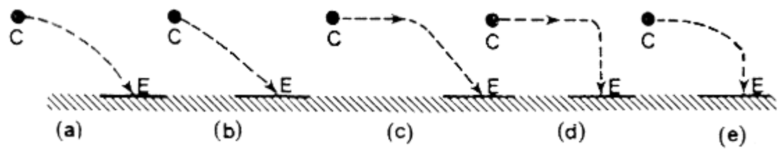
Den vänstra delen av figuren visar en boll X i rörelse. Bollen glider ned längs det lutande planet AB och sedan på ett friktionsfritt, horisontellt plan BC. Vid punkt C lämnar bollen planet. Luftmotståndet försummas.



(13) Bollens fart på det horisontella planet BC...

(a) är konstant.
(b) ökar hela tiden.
(c) minskar hela tiden.
(d) ökar en stund och är därefter konstant.
(e) är konstant en stund och minskar därefter.

(14) Vilken figur beskriver bollens rörelse efter att den lämnat det horisontella planet vid C?



(15) Bollens fart längs banan du valde...

(a) är konstant.
(b) ökar hela tiden.
(c) minskar hela tiden.
(d) är konstant en stund och ökar därefter.
(e) Inget av ovanstående svar är korrekt.

(16) Vilken kraft / vilka krafter verkar på bollen efter punkt C, längs banan du valde?

(a) Bollens tyngd, vertikalt nedåt.
(b) En horisontell kraft som upprätthåller rörelsen.
(c) En kraft vars riktning förändras i rörelsens riktning.
(d) Bollens tyngd och en horisontell kraft.
(e) Bollens tyngd och en kraft i rörelseriktningen.

Samtidigt som boll X lämnar det horisontella planet vid punkt C, släpps en boll Y (identisk med boll X) från samma höjd som C. Boll Y släpps från vila och faller vertikalt nedåt (se högra delen av figuren vid början av del 6).

(17) Var befinner sig boll X när boll Y når punkt D?

(a) På samma höjd som D.
(b) Ovanför D.
(c) Nedanför D.
(d) Det beror på hur högt punkten D ligger.
(e) Inget av ovanstående svar är korrekt.

(18) Vilken av bollarna X och Y når marken först?

(a) Boll X.
(b) Boll Y.
(c) De två bollarna når marken samtidigt.
(d) Det beror på hur högt punkten C ligger.
(e) Inget av ovanstående svar är korrekt.

(19) Vilken boll har högst fart när den når marken?

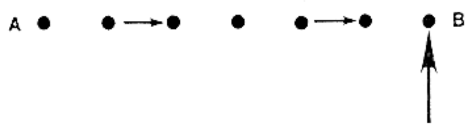
(a) Boll X.
(b) Boll Y.
(c) Bollarna har samma fart när de når marken.
(d) Det beror på hur högt punkten C ligger.
(e) Inget av ovanstående svar är korrekt.

(20) Om planet BC förlängs bortanför C, så att boll X aldrig lämnar planet, var skulle då boll X befinna sig samtidigt som boll Y når marken?

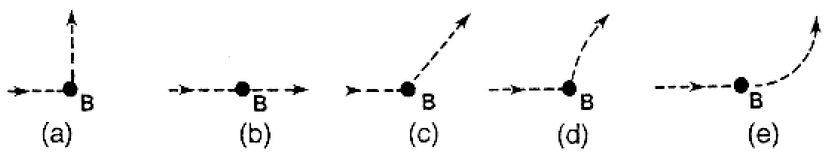
(a) Vertikalt ovanför punkten E, där boll X nådde marken i fråga 14.
(b) Höger om punkten E.
(c) Vänster om punkten E.
(d) Det beror på hur högt punkten C ligger.
(e) Inget av ovanstående svar är korrekt.

Del 7 (3 frågor)

I figuren tittar du ner på en platta som glider med konstant fart på en friktionsfri horisontell yta, från punkt A till punkt B. När plattan når punkt B får den en horisontell knuff i den riktning som den stora pilen visar. Luftmotståndet försummas.



(21) Vilken figur beskriver plattans rörelse på den horisontella ytan efter att den fått knuffen i punkt B?



(22) Farten plattan har precis efter den fått knuffen i punkt B är...

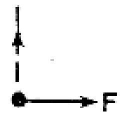
(a) lika med farten u som den hade innan den fick knuffen.
(b) Lika med farten v som den får från knuffen, oberoende av farten u som den hade innan knuffen.
(c) Mindre än båda farterna u och v.
(d) Lika med den aritmetiska summan (u+v) av farterna u och v.
(e) Större än båda farterna u och v, men mindre än den aritmetiska summan av farterna.

(23) Plattans fart efter knuffen, längs banan du valde...

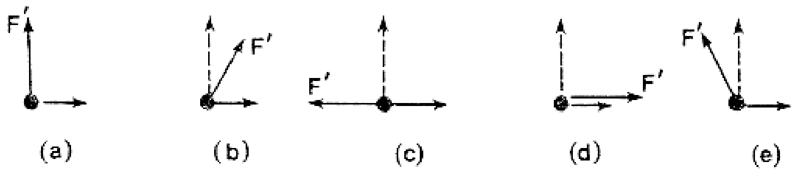
(a) är konstant.
(b) ökar hela tiden.
(c) minskar hela tiden.
(d) ökar en stund och är därefter konstant.
(e) är konstant en stund och minskar därefter.

Det 8 (2 frågor)

I figuren tittar du ner på en platta som glider på en horisontell yta. En konstant kraft F verkar på plattan, enligt pilen i figuren.



(24) För att plattan ska föras i riktningen angiven med den streckade linjen, måste en andra kraft F’ verka på plattan. Vilken figur visar hur kraften F’ ska verka?

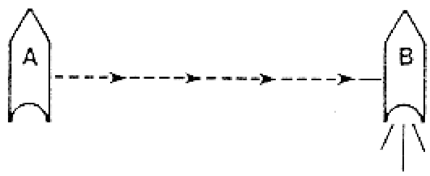


(25) Plattans fart längs den streckade linjen då de två krafterna verkar samtidigt...

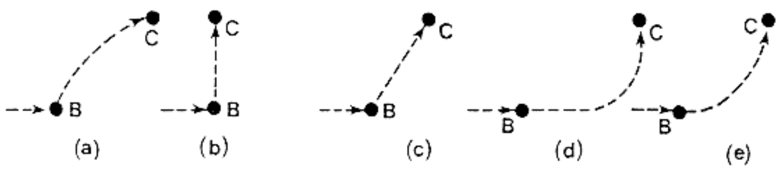
(a) är konstant.
(b) ökar hela tiden.
(c) minskar hela tiden.
(d) ökar en stund och är därefter konstant.
(e) är konstant en stund och minskar därefter.

Del 9 (4 frågor)

Figuren visar en raket som svävar i rymden i den streckade linjens riktning. Mellan punkt A och punkt B verkar inga yttre krafter på raketen. När den når punkt B startar raketen sina motorer enligt figuren, och färdas med motorerna påslagna tills den når en punkt C i rymden.



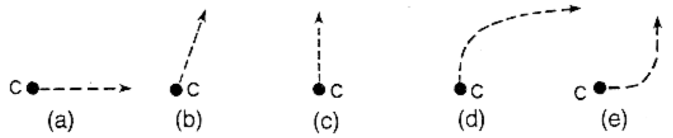
(26) Vilken figur beskriver raketens rörelse från punkt B till punkt C?



(27) Raketens fart då den rör sig från B till C...

(a) är konstant.
(b) ökar hela tiden.
(c) minskar hela tiden.
(d) ökar en stund och är därefter konstant.
(e) är konstant en stund och minskar därefter.

(28) Vid C stänger raketen av sina motorer. Vilken figur beskriver raketens rörelse från punkt C?

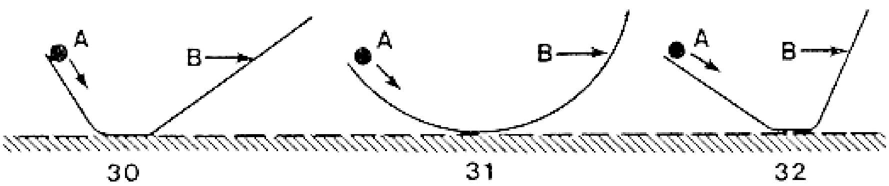


(29) Raketens fart efter punkt C...

(a) är konstant.
(b) ökar hela tiden.
(c) minskar hela tiden.
(d) ökar en stund och är därefter konstant.
(e) är konstant en stund och minskar därefter.

Del 10 (3 frågor)

De tre nedanstående figurerna visar friktionsfria ”skålar” som står på ett horisontellt bord. En boll släpps från vila från toppen A på den vänstra sidan i de olika ”skålarna”. Luftmotståndet försummas.

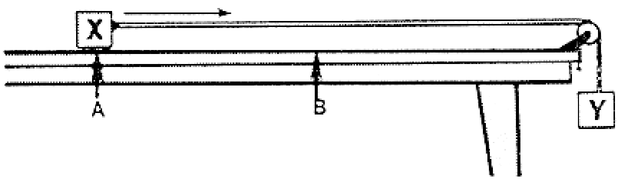


Frågorna (30) , (31) och (32): Vilken är den högsta punkt som bollen kan nå på den högra sidan i de olika ”skålarna”?

(a) Punkt B, som ligger på samma höjd som punkt A.
(b) Lägre än punkt B.
(c) Högre än punkt B.
(d) Det beror på hur högt punkt A ligger.
(e) Det beror på hur stor bollen är.

Del 11 (4 frågor)

Figuren visar två klossar, X och Y, förbundna med en masslös tråd som löper över en friktionsfri trissa. När kloss Y släpps, dras kloss X i pilens riktning på ett friktionsfritt, horisontellt bord. Luftmotståndet försummas.



(33) Farten hos kloss X...

(a) är konstant.
(b) ökar hela tiden.
(c) minskar hela tiden.
(d) ökar en stund och är därefter konstant.
(e) är konstant en stund och minskar därefter.

(34) När kloss X når punkt B går tråden av. Vad händer då med kloss X? Kloss X...

(a) stannar vid B.
(b) fortsätter med konstant fart.
(c) ökar farten.
(d) minskar farten.
(e) ökar farten en stund och minskar sedan farten.

Kloss Y byts nu ut mot en annan kloss Z som drar på kloss X med dubbelt så stor kraft än vad kloss Y gjorde. Kloss X placeras åter vid punkt A och släpps. När kloss X når punkt B så går tråden av igen.

(35) Vilken fart har kloss X vid punkt B jämfört med farten den hade vid samma punkt då kloss Y användes?

(a) Hälften så stor fart som den hade tidigare.
(b) Mindre än den tidigare farten, men inte hälften så stor.
(c) Lika stor som den tidigare farten.
(d) Dubbelt så stor som den tidigare farten.
(e) Större än den tidigare farten, men inte dubbelt så stor.

(36) Hur lång tid tar det för kloss X att nå punkt B när kloss Z drar, jämfört med den tid det tog för att nå samma punkt då kloss Y drog?

(a) Hälften så lång tid som det tog då kloss Y drog.
(b) Kortare tid, men inte hälften så lång.
(c) Lika lång tid.
(d) Dubbelt så lång tid.
(e) Längre tid, men inte dubbelt så lång.

Detta test är en översättning av ett test konstruerat av *I. A. Halloun* och *D. Hestenes*, som publicerades i *American Journal of Physics, vol 53, nr 13, november 1985*.

This test is a Swedish translation of the original test by *I. A. Halloun* and *D. Hestenes*, published in *American Journal of Physics, Vol. 53, No. 13, November 1985*.

Svarsblankett – Diagnostiskt test inom mekanik

Gymnasium	**Högskola / Universitet**
Linje/program:_______________________	Program:__________________________
Betyg i fysik:____________	Godkända poäng i fysik:__________
Betyg i matematik:____________________	Godkända poäng i matematik:_________
Avgångsår:________	
Ev. kompletteringar:__________________	Man Kvinna
(t.ex. basår eller komvux)	

	a	b	c	d	e	*Rättn*
1						
2						
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	a	b	c	d	e	*Rättn*
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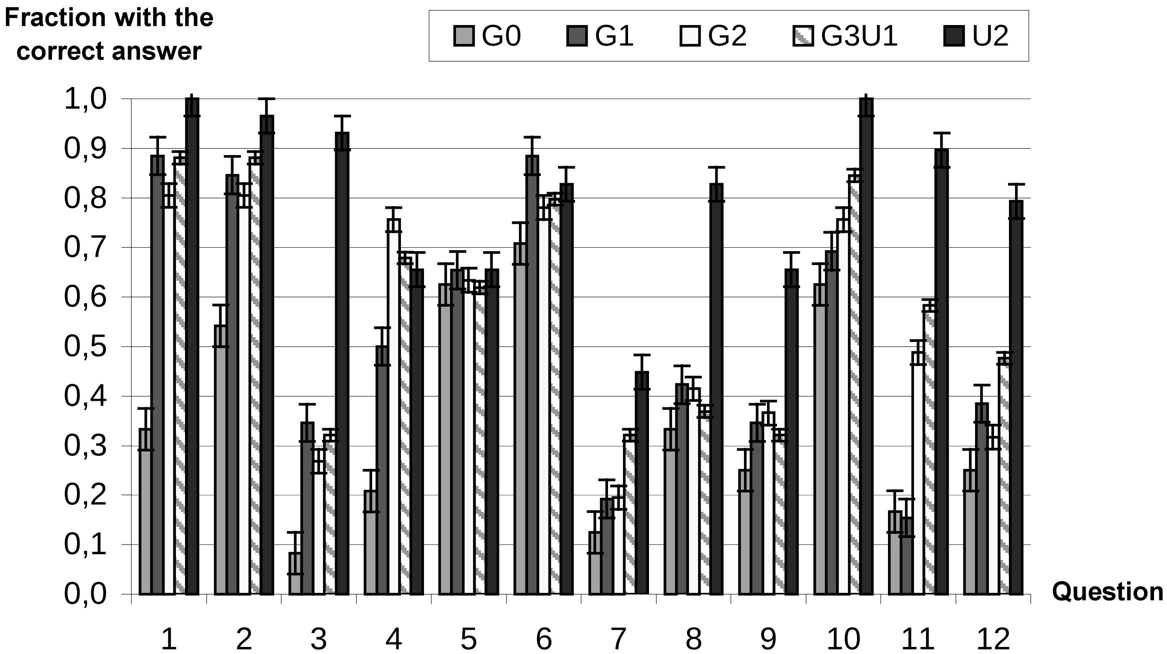
36						

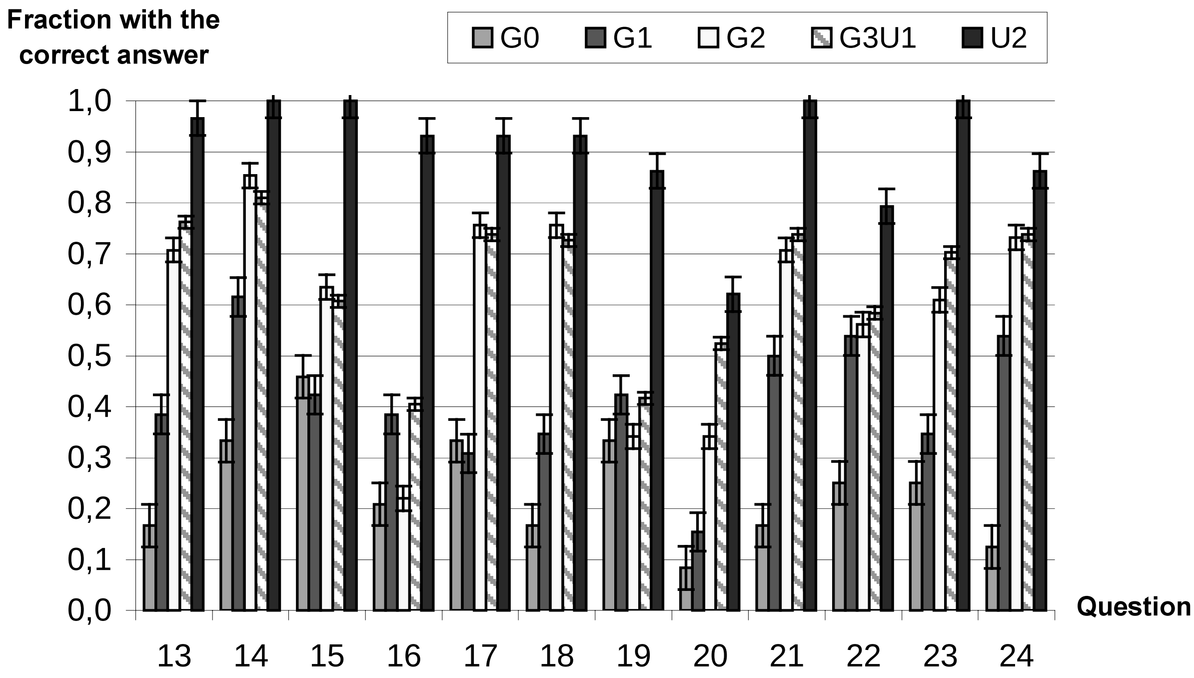
Appendix B

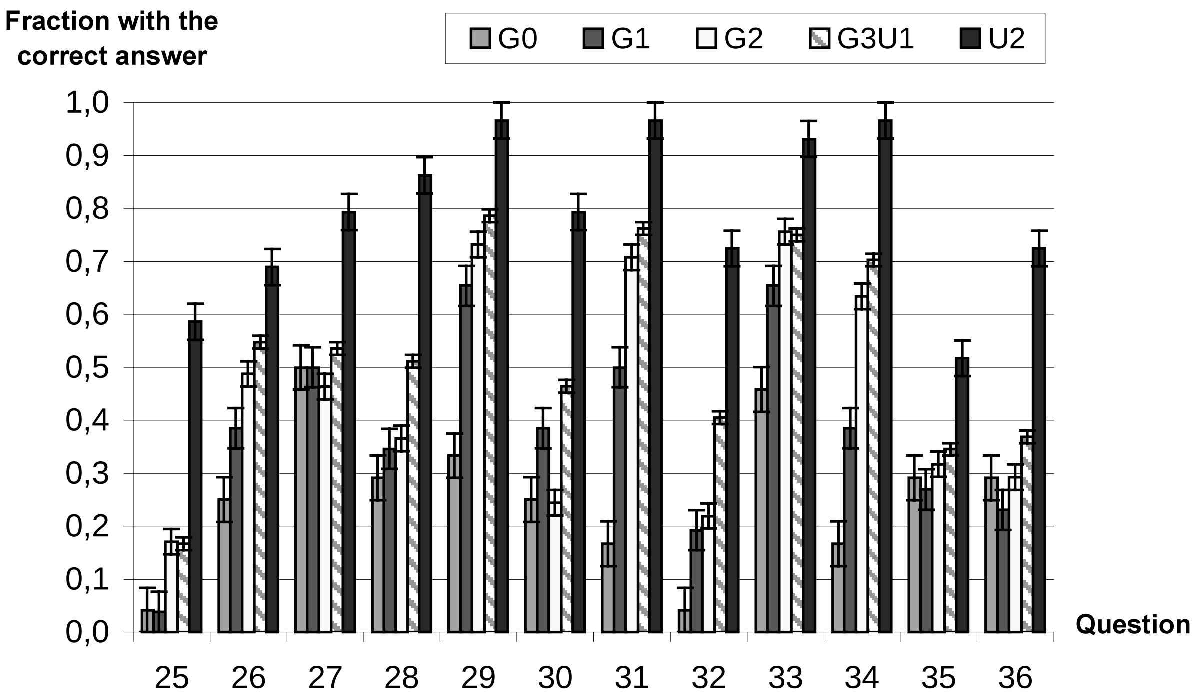
Fraction with the correct answer

As a help to find questions that can reveal concepts in classical mechanics that are difficult for students to understand, the fraction with the correct answer in the test groups has been used.

The three diagrams show the fraction with the correct answer in all test groups on all 36 questions. In the analysis of these results, 0.4 (±1 person) is defined as the upper limit for a low fraction. The bars indicate results corresponding to ±1 person.




Fraction with the correct answer
G0
G1
G2
G3U1
U2
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
Question
13
14
15
16
17
18
19
20
21
22
23
24


Fraction with the correct answer
G0
G1
G2
G3U1
U2
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
Question
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34
35
36

Appendix C

Quotes from students’ explanations

On some questions the students were asked to write a short explanation for their answers on the multiple-choice questions. Here some quotes from these explanations will be given, translated into English. The purpose of this is to show how students use physics concepts. Before each quote it is noted which part of the diagnostic test the explanation comes from and after each quote it is noted which group the student comes from.

Explanations about forces

Part 6 – “The force in the vertical direction is an accelerated movement.” (G2)

Part 6 – “Two types of forces exist; constant uniform motion and uniformly accelerated motion.” (G3)

Part 7 – “There are two forces u and v.” (G1)

Part 7 – “It has the original speed v_1 and the speed v_2 is added. The resultant force is bigger than both v_1 and v_2.” (G2)

Part 7 – “The force that ‘pulls’ the plate forward wants it to go on.” (G2)

Part 7 – “Some force is lost at the push.” (G3)

Part 9 – “The force that got the rocket to float…” (G0)

Part 9 – “The speed will be constant since the force is constant.” (G0)

Part 9 – “It floats with constant speed thanks to the forces in space.” (G3)

Part 9 – “When the rocket floats to the right, there has to be a force to the right from the rocket.” (U1)

Other explanations

Part 6 – “The ball’s weight affect the acceleration.” (G0)

Part 6 – “Because of the speed the ball has, it will come out a bit before it falls to the ground.” (G2)

Part 6 – “Gravity pulls the ball towards the ground, but the [horizontal] movement keeps it in the air longer than it would have if it had only been dropped.” (G2)

Part 6 – “The ball is affected by a constant uniform motion.” (G3)

Part 6 – “Due to the speed it has, the ball will not fall down directly.” (U1)

Part 7 – “The inertia ‘drives’ the plate to the right with constant speed.” (G2)

Part 7 – “Some of the speed disappears when the direction is changed.” (U1)

Part 9 – “The rocket is not affected by anything else than the speed it had to the right” (G2)

Part 9 – “When the rocket starts its engines it takes a while for them to get going.” (G2)

References

Brown, D. E. 1989. Students' concept of force: The importance of understanding Newton's third law. *Physics Education* 24, pp. 353-357.

Clement, J. 1982. Students' preconceptions in introductory mechanics. *American Journal of Physics* 50 (1), pp. 66-71.

Edgar, S. B. 1990. Classroom note. An invalid 'derivation' of the standard equation $x=½(v_0+v)t$. *International Journal of Mathematical Education in Science and Technology* 21 (1), pp. 167-168.

Finegold, M. and Gorsky, P. 1991. Students' concepts of force as applied to related physical systems: A search for consistency. *International Journal of Science Education* 13 (1), pp. 97-113.

Gamble, R. 1989. Force. *Physics Education* 24 (2), pp. 79-82.

Hake, R. R. 1998. Interactive-engagement versus traditional methods: a six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics* 66 (1), pp. 64-74.

Halloun, I. A. and Hestenes, D. 1985a. The initial knowledge state of college physics students. *American Journal of Physics* 53 (11), pp. 1043-1055.

Halloun, I. A. and Hestenes, D. 1985b. Common sense concepts about motion. *American Journal of Physics* 53 (11), pp. 1056-1065.

Halloun, I. A. and Hestenes, D. 1987. Modeling instruction in mechanics. *American Journal of Physics* 55 (5), pp. 455-462.

Hammer, D. 1996. More than misconceptions: Multiple perspectives on student knowledge and reasoning, and an appropriate role for education research. *American Journal of Physics* 64 (10), pp. 1316-1325.

Hasan, S., Bagayoko, D. and Kelley, E. L. 1999. Misconceptions and the certainty of response index (CRI). *Physics Education* 34 (5), pp. 294-299.

Hein, T. L. 1999. Using writing to confront student misconceptions in physics. *European Journal of Physics* 20 (2), pp. 137-141.

Jagger, J. M. 1987. Students Understanding of Acceleration. *Mathematics in School* September 1987, pp. 24-25.

Marquit, E. 1990. A plea for a correct translation of Newton's law of inertia. *American Journal of Physics* 58 (9), pp. 867-870.

McClelland, J. A. G. 1984. Alternative frameworks: Interpretation of evidence. *European Journal of Science Education* 6 (1), pp. 1-6.

McCloskey, M. 1983. Intuitive Physics. *Scientific American* 248 (4), pp. 122-130.

Peters, P. C. 1982. Even honor students have conceptual difficulties with physics. *American Journal of Physics* 50 (6), pp. 501-508.

Ploetzner, R. 1995. How misconceptions affect formal physics problem solving: model-based predictions and empirical observations. Published in Moore, J. and Lehman, J. F. (eds.), *Proceedings of the seventeenth annual meeting of the cognitive science society*, pp. 248-252. http://www.psychologie.uni-freiburg.de/signatures/ploetz/papers/cogsci.95.html (1999-10-25)

Terry, C. and Jones, G. 1986. Alternative frameworks: Newton's third law and conceptual change. *European Journal of Science Education* 8 (3), pp. 291-298.

Thijs, G. D. 1986. *Conceptions of force and movement: A study of intuitive ideas of pupils in Zimbabwe in comparison with findings from other countries.* Amsterdam: Vakgroep Algemene Vorming, Vrije Universiteit. AV rapport nr. 5.

Williams, H. T. 1999. Semantics in teaching introductory physics. *American Journal of Physics* 67 (8), pp. 670-680.