Aristotle still wins over Newton

An evaluation report of a new, simulation-supported approach to teach the concepts of inertia and gravity

Hermann Haertel.
Guest scientist at: Institute for Theoretical Physics and Astrophysics,
University of Kiel, Germany
haertel@astrophysik.uni-kiel.de
Co-Authors:
Marian Kires, Zuzana Jeskova, Jan Degro
University of P. J. Safarik, Kosice, Slovakia
Yuri B. Senichenkov
Polytechnic University, St. Petersburg, Russia
Jose-Miguel Zamarro
University of Murcia, Spain

***Abstract*-- Evaluation studies of the results of physics instruction show quite clearly that concepts derived from daily life, sometimes known as misconceptions, are rather robust and - for the majority of students resist all attempts at change through instruction.**

A particularly outstanding misconception is the ancient view of the origin of motion, which dates back to Aristotle. He stated: "Every movement needs a mover" and this concept, which in mathematical form can be expressed as F=mv, is deeply rooted in the minds of modern students, even after they have finished a mechanics course.

Some members of the CoLoS (Conceptual Learning of Science) international association decided, as a first step, to test whether these findings could be replicated across our different school systems. In brief, our data are fully in agreement with the well known observation. We also found out that most of our students do not differentiate between inertial mass and gravitational mass.

Some learning material enriched with simulations and computer generated animations were developed to cover the topics "Inertia" , Free Fall" and "Satellite movement". The special feature of these simulations consists of the fact that, instead of neutral objects in a gravitational field, we simulated the movement of charged objects in an electrical field. Under such circumstances the effect of inertial mass and attracting force can be effectively separated and studied in detail before they are combined in a mechanical world with gravity and no charge.

An evaluation has been administered in four different countries under controlled conditions with 9 groups and a total of 103 students.

The results of a delayed post test are positive but a little below our expectations. Hints for further improvement can be derived.

Index Terms-- Evaluation, Gravity, Inertia, Multi Media

I. THE TEACHING / LEARNING PROBLEM

Many different studies and own tests [1]-[5] have shown that the majority of our students do not have sufficient knowledge about basic concepts in mechanics even after having completed an intensive course in mechanics at upper secondary level.

When asked about forces and movements, only a minority can base their answers on the fact that the sum of all forces is zero for a movement of constant velocity and that a constant acceleration is related to a constant force. The majority prefers to follow the old statement of Aristotle, saying that each movement needs a mover or they relate a changing velocity with a changing force.

Furthermore, the vast majority of our students give rather strange explanations for the fact that all objects experience the same acceleration in free fall. Either it is a fact that mass does not play a role, or it is the vacuum where special laws apply or similar reasons. Rather seldom a distinction is made between inertial and gravitational mass and only a few students mention as explanation that the ratio of inertial and gravitational mass is constant.

The deficit, stated here is probably not due to an insufficient preparation of the content or an insufficient method of teaching. Our guess is that the reason for these negative learning results can be found in the fact that matter and mass are experience in our daily life as something uniform and consistent. In the physics class inertia and weight is only separated conceptually but cannot be separated experimentally. Since both are proportional to each other they are soon be unified again and cancelled on both sides of mathematical equations. It seems that most of our students do not follow this theoretical discourse and only learn short-cuts like "in free fall mass does not play a role."

We claim that this is a rather unsatisfying situation which should be improved if possible.

II. CONCEPT

A solution for this didactical/experimental dilemma can be found by using a simulation, were the gravitational fields is replaced by an electrical Coulomb field and the gravitational mass by the electric charge.

Under such condition it is for instance possible to simulate a free fall as some kind of Millikan experiment in space, where only Coulomb forces are acting and gravity does not apply. Under such conditions it is possible to vary independently the applied force and the inertial mass in order to study the importance of the ratio of f/m for equal acceleration in free fall.

To simulate the movement of a satellite orbiting around the earth, the same idea can be used. The satellite can be treated as a charge object circulating around an oppositely charged central body while gravity is neglected. Here again the influence of the centripetal force f can be studied independent of the inertial mass m and vice versa . Again the students can detect the importance of the ration of f/m to keep the satellite on the same constant orbit.

Teaching material was developed to implement this idea and this under the following conditions:

1. The developed materials should first be evaluated under controlled conditions before being published.

2. The material should be evaluated in different countries to reveal its unique added value, if any, which does not depend on the influence of the external school system. This could be done because some members of the CoLoS group [6] decided to carry out this evaluation in Germany, Russia, Slovakia and Spain. With this study no ranking between the participating schools is intended.

3. The materials should be designed for a learning situation where a single student is working in front of a computer while the material is present on the screen and as hard copy. In addition simulations and computer generated animation should be offered to support the learning process. The material should be presented in such detail that students can learn on themselves without any permanent support of a teacher. If help is needed the researcher/physics teacher who is supposed to be present should give any necessary support but should not intervene by him/herself.

This last condition is needed only for the purpose of an evaluation where the influence of the teacher should be reduced as much as possible. Under normal classroom conditions the materials can of course be used without these constrictions and can be adapted to local conditions.

III. DEVELOPMENT OF THE MATERIAL

In a first step the material was designed for 3 units of 90 minutes and tried out with small groups of students in all involved countries.

Based on these pre-studies we concluded that the material in its actual form is quite demanding for most of our students. In all these tryouts positive learning results could be stated which were encouraging enough to start a second evaluation round. The following conclusions were drawn for a revision:

- The simulation based material in its actual form is quite demanding in respect to self contained learning and may be asking too much for many students. More support and guidance for the use of simulations is needed.
- The isolated situation of single students in front of a computer may have had a negative influence on the learning outcome. The structure of the material should therefore support a discussion and co-operation among small groups.
- School internal restrictions allowed only for an allocation of 2 learning session and 2 test session. The material therefore had to be reduced to a minimum with less time for exploration or redundance.

The revised 2nd version of the material was enriched with questions and assignments to stimulate group discussion. The teacher is asked to look for appropriate progress in respect to the limited time schedule and if necessary to lead a classroom discussion in order to keep the different groups together.

The interface of the simulations was simplified and the text was concentrated on the topics “inertia” “free fall” and “satellite movement”.

IV. REMARKS ON THE MATERIAL

The material is divided into a series of learning steps, which are enriched by questions, supportive text, simulations and computer generated animations. The simulations offer the possibility (see fig.1) to vary independently the inertial mass of an object and the applied force.

As a typical assignment the students are asked to find out, under which condition different objects with different mass will experience the same acceleration.

The computer generated animations show different scenes, familiar to the students (raising bubbles, driving car, gliding aeroplane), and visibly emphasize the fact that if v=const. then Σf=0.

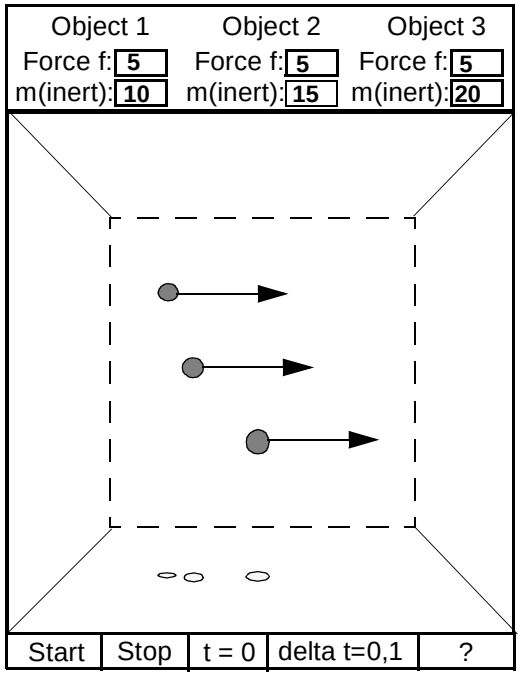

Fig. 1: Simulation to apply different forces to objects with different mass

All the material is available on the net. All text files are offered in html and pdf format, so that students can read either from the screen or from a printout. These two formats seem to be meaningful and often even necessary because for many students careful and concentrated reading is only possible from paper while they are used to browse through any text which appears on the screen.

The simulations as applets need a java activated browser.

V. EVALUATION SETUP

The evaluation took place at the cities Kiel (Germany), Murcia (Spain), Kosice (Slovakia) and St. Petersburg (Russia). The materials and interfaces were translated to the local languages and the evaluation was carried out under controlled conditions.

A pretest consisting of three parts was administered were knowledge about the 1. and 2. Newtonian principle was tested. Furthermore it was asked, if students can give a satisfying explanation for the fact that the acceleration in free fall is the same for all material objects.

Newton´s principle had been treated for all students during the physics course some weeks or months before. The pretest therefore constitutes a retarded post test for the learning outcome of previous physics lessons.

After a learning phase, based on the developed materials of 2 x 90 min and the students working in pairs in front of a computer, a retarded post test with a minimum delay of 2 weeks was administered as a parallel version of the pretest.

VI. EVALUATION RESULTSn

The tests

Altogether 103 students of 9 groups took part in the evaluation and finished a pre and post test of 3 parts.

The first part, consisting of 6 items, comprises questions about the 1. and 2. Newtonian principle. Do the students know that for a moving object with constant velocity the sum of all applied forces is zero? Furthermore it is tested if the students can decide about the direction of the applied force for a given direction of the velocity and its change.

The second part comprises the same kind of question with two additional difficulties. The number of choices is increased and these choices are not presented in words but in the form of force/time diagrams.

The third part of the test comprises questions about the topics “gravitation”, and “ratio of force and inertial mass”.

For part I and II the answers have not only been evaluated in a Newtonian perspective but also in a so-called Aristotelian view. In such a view the following conditions are supposed to be correct:

1. To keep up a movement with constant velocity, a constant force has to be applied.

2. For a movement with a linearly changing velocity, a linearly changing force is needed.

These assumptions correspond to our experience in daily life, where only the driving forces are observed while the friction forces are neglected. The question is if physics teaching can influence these daily life concepts, which have proven to be rather stable.

The results

The results of part I and II are presented together since no difference could be found besides the fact that the results of part II are slightly lower. Since this part was slightly more difficult in its form, such differences could be expected.

In average over all items and broken down for the different groups, the following results were found for the part I/II and III.

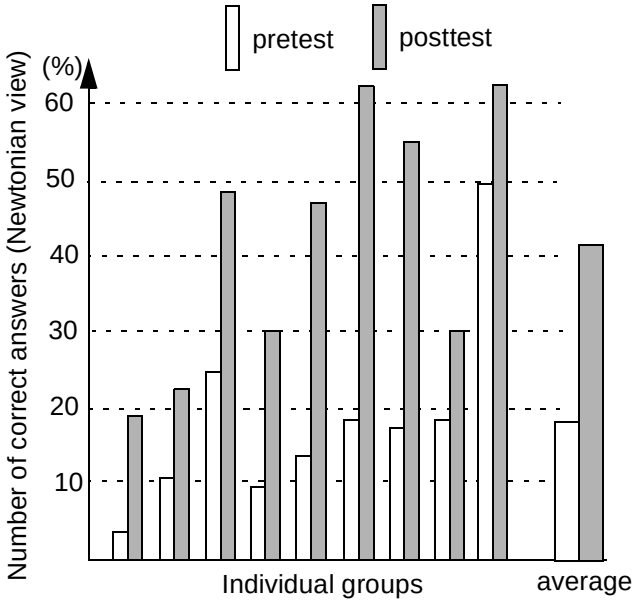

Fig. 2: Results of part I and II - Newtonian view

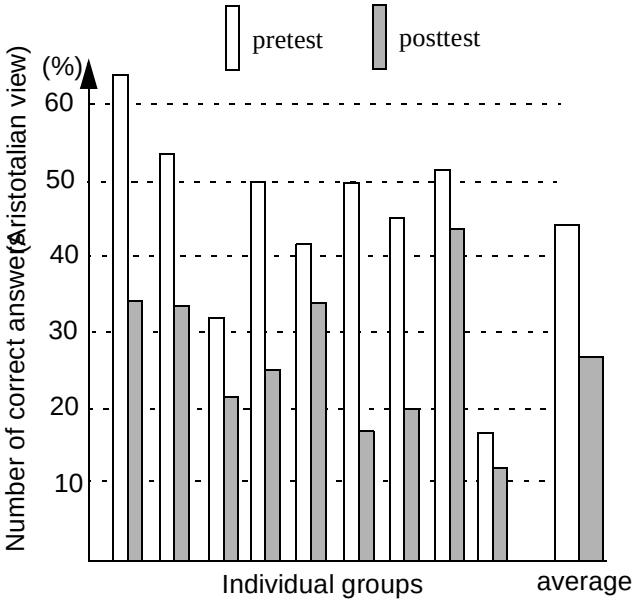

Fig. 3: Results of part I and II - Aristotalian view

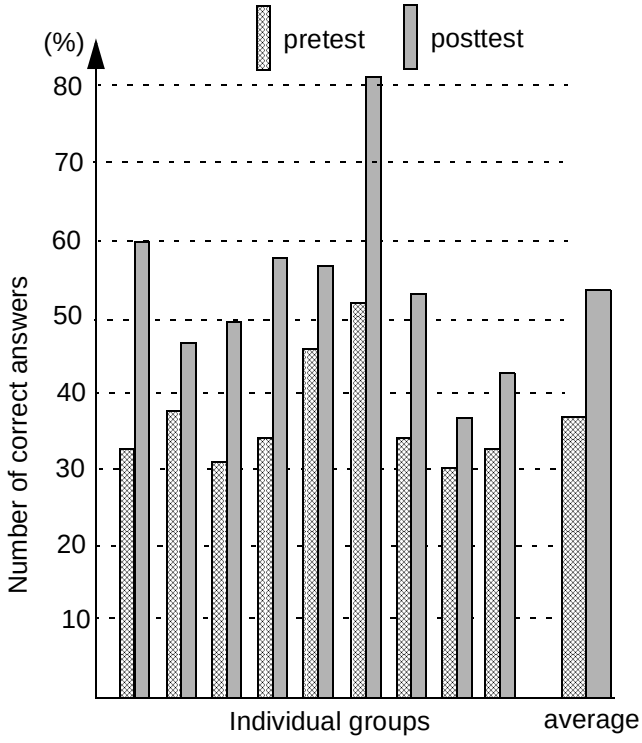

Fig. 4: Results of part III - gravitational mass/inertial mass

VII. DISCUSSION

Part I and II - velocity, acceleration and force

The results of the pretest (fig.2) vary between 3% and 50% for the different groups with an average of 18% (stdev.=14%).

The number of correct answers in an Aristotelian view are higher in all groups (fig. 3). The results vary for the pretest between 17% and 63% for the different groups with an average of 45% (stdev. = 14%).

In the light of the fact that all participating groups had attended a course in mechanics, two conclusions can be drawn:

1. The efficiency of traditional teaching in different schools seems to be rather different in respect to the teaching of Newton‘s basic principles (if v=const, then $\Sigma F=0$;if a=const then ΣF=const)

2. Even in the best group only every second student has acquired a knowledge about these principles which is stable enough to be reflected in a retarded test. For the majority of our students, however, it can be stated that their daily life concept about velocity and force seems to be persistent and to outlast any influence from physics lessons.

After the learning session and at least two weeks later a posttest was administered. In average over all participating groups we found an increase of correct answers (newtonian view) of just under 25% with a variation between 11% and

45% (stdev=13%) The number of correct answers in an Aristotelian view after the learning phase are lower in all groups (fig 3). In average over all participating groups we found a decrease of 18% with a variation between 4% and 32% (stdev=11%).

This result falls short of our expectation and makes clear that the intended change from a daily life concept to a scientific one cannot be performed for a large part of our student during a single learning step. The experience in daily life that a constant force is needed to keep an object moving has to be judged as a rather powerful one with a persistent influence on the way our students conceptualise mechanical problems.

A first hint for an improvement of these learning results was found in an additional post study, where the same content was repeated during a 45 min session with 2 classes. This activity produce improved results, found in a retarded post test, where visibly more than half of the students now delivered correct answers.

Part III - gravity, inertial mass, gravitational mass

As shown in fig.4 the number of correct answers increased in average by just under 20% (stdev.=10%). The content was presented during a learning phase of 90 min and the post test was retarded by at least 2 weeks.

This result too falls short of our expectation, since the working atmosphere and the discussion among the students during the learning phase seemed to be rather productive. It shows that rather severe problems of understanding show up when knowledge about basic concepts in mechanics like inertial and gravitational mass have to be understood. Obviously many of our students cannot overcome these barriers during a single learning phase.

It needs to be tested if additional short repetitions of the essential principles and repetitive demonstrations of our developed simulations will produce improved result.

When comparing our evaluation with normal classroom activities it has to be considered that the results have been achieved under more difficult conditions than usual. A teacher was missing who could have controlled and supported the learning process and the students administered the retarded test unprepared.

Under the guidance of a professional teacher and with the usual preparation phase shortly before the test, improved results can be expected.

REMARKS ON FUTURE CLASSROOM ACTIVITIES

During the evaluation the students discussed and answered the listed questions on their own. Such a discussion can certainly be organised with the whole class and guided by the teacher where new questions can be raised and outstanding answers can be highlighted.

For school internal restrictions the evaluation had to be limited to 2 learning session of 90min each. This amount of time is a minimum which may have to be extended under usual conditions. This especially holds for the necessity, mentioned above, that the content of these lessons should be presented no only once but repetively. This would also correspond with the idea of learning as an active constructive process [7][8], which certainly will need time and repition. To structure such repitions the developed video clips could be quite helpful. In addition to the three clips, used during the evaluation, the following topics have been added in the meantime:

- a ship, entering a harbour
- a motor boat on a river
- a balloon drifting with the wind
- a skydiver hanging on an open parachut

The daily experience is stabilizing the Aristotalian view of motion and is blocking an understanding of the scientific Newtonian perspective. If these videos are repetitively shown over a longer period of time, the daily life experience is brought into the classroom and can repetitively be discussed and revised. The results of our evaluation give rise to the hope that by applying this procedure the majority of our students may improve their understanding of the basic laws of mechanics in comparison with the actual state.

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