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Effectiveness of Practical Work in the Remediation of Alternative Conceptions in Mechanics with Students in Botswana.

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1 INTRODUCTION

In science education a multitude of aims is pursued through practical work (Hofstein and Lunetta, 1982; Woolnough, 1991). Three categories of aims can be distinguished. *Cognitive* aims pertain to the development of problem solving skills, learning of scientific concepts and understanding of science and the scientific method. *Practical* aims involve the development of skills in performing investigations, skills in analyzing data and communication and cooperation skills. *Affective* aims are directed at enhancing attitude and motivation towards science and promoting a positive perception of one's ability to understand and influence the environment.

Through research the positive effect of practical work on the development of practical skills and, to some extent, enhancement of attitudes toward science has been confirmed. However literature shows that the effect of conventional practical work on the cognitive development of students is probably very limited (Kempa, 1988; Hodson, 1990; Woolnough and Allsop, 1985).

Yet, within the constructivist view on learning of concepts in general, the question on the role of practical work aimed at the learning of scientific concepts has gained renewed interest. In this view learning is seen as a process in which the student modifies and restructures his or her existing understanding on the basis of new or newly interpreted information, thus constructing new understanding. Teaching aims to stimulate and foster this process, while attempting to guide towards new understanding that is more in line with the 'correct' scientific view.

The use of a constructivist approach in effecting conceptual change through the use of science experiments is recommended by Gunstone and

Champagne (1991). In line with this view, a practical that aims to teach understanding of concepts will stimulate students in explicating their existing ideas and in constructing new or modified understanding based on laboratory experiences, rather than merely illustrate or explain the scientific viewpoint. Such a practical may, in contrast to 'traditional' practicals, contribute to the students' conceptual understanding.

In this paper we will use the term 'practical work' to indicate any teaching/learning activity that involves the execution of physics experiments in the classroom. The central research question is: *What role can be played by practicals in the process of conceptual change?* First we will discuss models to structure practical work in a constructivist approach, aimed at conceptual change (Possner et al., 1982; Driver, 1989). In section 3 we will describe the background of research. Section 4 outlines the aims of research, section 5 the methodology. The effectiveness of practicals was studied both qualitatively and quantitatively, using tests, student interviews and classroom observations. We will give the results in section 6. In section 7 we will draw preliminary conclusions regarding the large-scale effectiveness of the practicals studied, the quality of student understanding that was gained and the comparison of small group practicals and teacher demonstrations.

2 PRACTICAL WORK FOR CONCEPTUAL CHANGE

From literature we may extract at least two conditions that must be satisfied by practical work aimed at conceptual change:

Practical work must be aim-specific.

Van den Berg and Giddings (1992) point out, that practicals aimed at conceptual change will differ markedly from practical work that aims to teach process skills or to train manipulative skills. They outline the specific requirements that the teaching aims of each of these types will impose on the design of the practical and the teacher guidance students receive. Accordingly, they distinguish 'concept labs', 'process labs' and 'skill labs'. A necessary condition for a 'concept lab' to be effective is that students already master the process and manipulative skills they will use in it to a sufficient degree.

Practical work must stimulate the process of constructing new understanding.

A common structure can be identified for the practicals aimed at conceptual change, as proposed in literature. This structure mirrors the structure of the process of knowledge-construction by the student, as proposed in the constructivist view (Driver, 1989). The structure may be characterised briefly by the following elements:

* Students are asked to *predict* the outcome of the experiment or describe a situation that is similar to the experiment. Thus students are made more aware of their existing ideas, and stimulated to commit themselves to those ideas.
* *Observations* are performed, that disagree with intuitive student ideas. If there is a discrepancy between the ideas and observations, the student is to become aware of that discrepancy. This awareness is called '*dissonance*' (Clement, 1987) or 'cognitive conflict' (Stavy and Berkovitz, 1980). A student experiencing 'dissonance' may be willing to search for scientifically more correct rules or explanations.
* Next, at least one way out of this situation of 'dissonance' must be available to the student. The 'way out' may be offered e.g. by direct interpretation of the results, by reasoning about analogous situations or by conducting further experiments. The 'way out' involves *formulating a tentative conclusion*, that to the student makes sense, at least on the level of being able to explain the data.
* The fourth step will involve a *test of the conclusion*. This could include explicit comparison of the conclusion and originally existing ideas in view of the experimental evidence, testing of the conclusion in further experiments or by applying it in paper exercises, and comparing the conclusion with ideas not considered so far, about similar situations. Thus, the conclusion may reach the status of a *new rule*.
* Finally the rule should not only make sense but also prove to be a useful instrument in reasoning about and explaining phenomena not studied in the lab. That is, the student should obtain at least a partial idea of the *range of applicability* of the new rules and their possible *generalisations*.

From a constructivist point of view we must assume that the extent to which the process is successfully executed by the student determines the extent to which cognitive change occurs for that student. The process is individual and requires that the student has an attitude of feeling responsible for her/his own learning. Teaching cannot force it, but may facilitate and stimulate its occurrence. It may also provide guidance and assistance to the student that engages in it.

'Concept labs' have in common that they aim for the same process: through the creation of 'dissonance' and logical or analogous reasoning, a better conceptual understanding may be achieved. However, different strategies may be followed, leading to different models for 'concept labs'. These are discussed in the next section.

2.1 Models of practical work aimed at conceptual change

Regarding the design of a 'concept' practical several models have been proposed in literature, according to which the process of knowledge-construction may be guided. Of particular interest in the context of this research is the model based on creating 'cognitive conflict' (Stavy and Berkovitz, 1980; Rowell and Dawson, 1981; Nussbaum and Novick, 1982; Stavy and Cohen, 1989; Dreyfus et al., 1989; Chinn and Brewer, 1993) and the 'anchor-bridges' model (Clement, 1987; Clement et al., 1989; Stavy, 1991; Brown, 1992; Treagust, 1992).

In the '*cognitive conflict*' *model*, the practical contains experiments that aim to show unequivocally and immediately the incorrectness of students' intuitive ideas. Subsequently it is attempted to generalise the findings into a new rule for the 'target'-situation. By testing the rule in analogous situations and linking to other student conceptions, the new rule may settle as a robust type of student knowledge, integrated into the existing cognitive network.

The '*anchor-bridges*' *model* aims to build understanding from 'anchor'-situations that most students describe correctly using intuitive ideas, towards 'target'-situations that are initially incorrectly or incompletely described. The 'anchor' and 'target' situations are analogous for the physicist, but not for the student. One or more 'bridging' situations are provided, that are more obviously analogous to both 'anchor' and 'target'. The 'anchor-target' analogy is divided into smaller steps, that make it easier to grasp. The student should be made aware (dissonance) that in passing these bridges (s)he has come to change his/her views as regards the 'target' situation.

The first model attempts to modify or replace the incorrect intuitive idea by a frontal attack on it. The second model tries to reach the same goal using careful step-by step reasoning based on correct student ideas. Stavy and Cohen (1989) find both strategies to be effective, but point out the risks of each. On one hand, students may loose self-confidence in 'conflict'-practicals. On the other, they may be unaware of conceptual change in 'bridging'-practicals.

We wish to consider a third model here, that has to our knowledge not been described in literature before. It involves practical work that aims to teach students the *distinction* between quantities, e.g. the distinction between a quantity and the rate at which it changes. In that case, it may not be possible to create an immediate conflict between expectations and observations, as the expectations would be too vague and undifferentiated. On the other hand, since the aim is showing that the quantities are **not** analogous, it would be difficult to conceive of 'conceptual bridges'. We will describe a practical that aims to show students the distinction between speed and acceleration. This involves creating dissonance using analogous reasoning. Resolving dissonance is attempted through new observations of the same experimental situation that was used in creating dissonance. Students are guided to describe these new observations in more detail, differentiating aspects that were not previously deemed relevant (by the students).

The more detailed description of the observations should enable the students to distinguish the quantities that were initially mixed up or muddled, thus improving the quality of their perception. We tentatively suggest to call this an '*enhancing of detail*'*-model*.

2.2 Teacher demonstrations and small group practicals

Practical work may be executed as a teacher demonstration or as a small-group practical (abbreviated as 'SGP' in this paper). The strategies differ in the relative strength of the teacher and student 'framing', i.e. the degree of control teacher and student have over selection, organisation and pacing of the knowledge in the teaching/learning process (Bernstein 1971). Teacher demonstrations we define here as practical activities that are strongly teacher framed, while small group practicals are strongly student framed. In their review of studies comparing the relative merits of teacher demonstrations and SGP, Garrett and Roberts (1982) conclude that '*in general no significant differences were found between the two tactics.. [that] the most consistent indicators were that teachers and materials were more important factors in causing any difference than were the tactics*' (p.136). In only a few of the reviewed studies some differences between teacher demonstrations and SGP were reported. Yet, the question becomes interesting again if practical work is designed from a constructivist approach. It will be necessary to specify what is meant exactly by demonstrations and SGP in a constructivist approach. E.g. by 'demonstration' we do not mean the conventional 'show' that allows the teacher to exhibit his expert knowledge.

Consideration of the teaching mode in the discussion on the role and value of practical work, is of special importance in the context of low-income countries (Woolnough, 1991; Kahn, 1990). It may be that for the training of practical skills, individual or SGP work cannot be replaced by other teaching activities. It is not obvious however, that practicals aiming for conceptual development cannot be replaced by other activities such as teacher demonstrations, which may be cheaper as less equipment is needed. A comparison of the effectiveness of teacher demonstrations with SGP aiming for concept learning can constitute relevant information at a time when the necessity and usefulness of SGP work is no longer considered to be obvious.

2.3 Advantages and disadvantages of the teaching modes

Thijs and Bosch (1993) note that in SGP, the process of actively constructing 'new' conceptions may be expected to run optimally, as the student is to a great extent individually responsible for the learning process. They also note possible disadvantages of SGP: students may carry out the experiment incorrectly, be unaware of discrepancies between expectations and observations, may carry out sections of the practical as isolated parts, and fail to realise how they are linked. In addition in SGP, the experiment is likely to confirm what students already think they know (Solomon, 1988). Student preconceptions may result in the denial of experimental evidence. Finally, even when all small groups obtain proper results, differences will remain between the observations of small groups, that may complicate discussions on interpretation and evaluation of the results.

All of these problems may to some extent be avoided in demonstrations, where the teacher has more control over performance of the experiment, and is able to point out essential aspects of the observed phenomena. Thijs and Bosch (1993) name as the main disadvantage of demonstrations that students themselves do not get a chance to manipulate the materials, and may be less challenged and more passive. This may result in an experience that is less personal, and therefore perhaps less memorable. A second possible disadvantage is the forced synchronisation of activities in demonstration practicals. As the class proceeds as a whole, individual students may miss the point in demonstrations because they are thinking at a different pace and not yet ready to appreciate it. We will specify the teaching modes further in section 5.3.

2.4 The teaching mode in relation to the process of constructing understanding

Ideally, a teacher will provide stimulus and proper guidance to each individual student at the right time. However, in large classes this is no longer feasible. In SGPs, the teacher can only attend to one group at a time, and will be unable to follow the whole process of meaning-construction of each student. In demonstrations however, provided that the teacher is able to involve all students in the process and is able to keep the right pace, the teacher has more opportunity to provide accurate and timely guidance. In as far as the process of constructing meaning can be controlled, the teacher has more control in demonstrations.

The content and structure of a practical may determine the need for teacher guidance. If the discrepancy between observations and expectations is immediately obvious, while the new rule follows directly from the data, students will need the teacher less. On the other hand, if the practical follows a coherent sequence requiring logical reasoning, the importance of guidance will increase. We therefore expect, that demonstrations could be more effective teaching modes than SGP if the steps in the process of constructing meaning involve reasoning rather than direct interpretation of data.

This implies that we expect teacher demonstrations to be at least as effective as SGP, provided that the teacher is able to maintain the involvement of all students, and an atmosphere allowing a free exchange of student ideas and explanations. Note however that we are limiting ourselves strictly to a discussion of practical work aimed at conceptual development ('concept labs'). 'Effectiveness' is defined merely in terms of the conceptual change that occurs due to the practical. The situation may be quite different for practicals that aim to develop process skills, where it may be essential that students themselves are able to handle the equipment.

3 BACKGROUND OF RESEARCH

This paper reports on research carried out in connection with practicals that aim to remedy a number of student ideas related to the concept of 'force'. The practicals were carried out in the Pre Entry Science Course (PESC) at the University of Botswana. Between O-levels and Science Year 1 students in Botswana follow the compulsory 6-month PESC at the University (Cantrell et al., 1993). PESC is part of a basic science programme, that was developed over the past 15 years by the Vrije Universiteit, Amsterdam, (VUA) together with a number of partner universities in Southern Africa and Indonesia (Thijs et al., 1993). PESC aims to provide students with sufficient knowledge and skills for a science or mathematics study at the University. Within the physics component of PESC, understanding of the concept of 'force' is one of the main teaching aims. Whereas the practicals studied here address only a limited number of student ideas, it is noteworthy that the general ideas found among students entering PESC show a close match with many ideas regarding force and motion found elsewhere, such as reported in the taxonomy given by Halloun and Hestenes (1985).

In the period 1988-1991 a large number of modifications in the physics-part of PESC was carried out, especially in mechanics. These changes were guided and monitored by yearly pre and post course tests, testing qualitative student understanding of elementary mechanics. Early results (Smith, 1989) showed that the course was rather ineffective in addressing alternative student ideas, prompting e.g. an expansion of teaching time for 'force and motion', the introduction of computer software for both simulation and data-handling and the production of teaching materials focusing on problems that the textbooks in use did not address (Thijs et al., 1993). Perhaps even more important than these 'material' modifications was the gradual change that occurred in teaching approach and strategy in order to teach for conceptual understanding. In varying degrees of success, it was attempted from 1989 to use a 'constructivist' approach (Driver et al., 1985) to teaching. Whereas the changes did successfully address many problems, they were deemed insufficiently effective in a number of cases. In particular, the following were found to be resistant to course changes thus far:

1. *Induced forces are often not understood.*

For the case of an object at rest on top of a sturdy support, results obtained from pre/post course tests in the period 1988-1991 showed that PESC students without much problem identify an upward and downward force, and state that those are equal in magnitude. However, in agreement with results reported by Van Genderen (1989) it was found that if the support bends under the (stationary) load, many students state that the downward force is bigger. Another student idea that was found is that in case an object is being pushed but remains at rest, the force preventing the motion exceeds the force that would cause motion to occur.

2. *A lack of qualitative understanding of acceleration.*

'Acceleration' is not a new quantity for PESC students, many of them are quite able to correctly define it and apply its formula. Yet, their qualitative understanding is insufficient. In answering qualitative questions about moving objects, many students say that if the speed increases (decreases), then so does the acceleration. Even more complicated confusions of speed and acceleration occur, as will be illustrated.

3. *'Impetus'-ideas about force.*

In many real life situations of moving objects, forces work along with the motion as well as opposite to it. Many students that do identify these forces believe that the forward forces must exceed the backward forces in order for the object to move. This is believed to be so irrespective of whether the motion is accelerated, decelerated or uniform. It is believed that the difference between forward force and backward force must be bigger if the speed of the object is higher. Closely related is the idea, that when an object is launched, it receives a force that maintains its motion. If the object moves horizontally over a surface, this force is present until it stops. For a projectile, most students say the force is there until it reaches the highest point in its motion, while gravity takes over from there. The frequency with which students use these ideas is determined with a pre course test, about 7 weeks before the practical.

It was decided that in order to address these ideas the introduction of practical work could probably be effective. For each of the above ideas, a practical was introduced in 1991. We will refer to these practicals as P1, P2 and P3, respectively. In 1992, the present in-depth study of the effectiveness of these practicals was piloted.

4 AIMS OF RESEARCH

In this paper we will try to answer the following questions:

1. How effective is each of the practicals in reducing the use by students of these intuitive ideas, and increasing the use of the physically correct ideas?
2. Is there a difference in effectiveness between teacher demonstrations and small group practicals?

The answers to these questions will be of a preliminary nature, since retention effects for the 1993 results cannot yet be determined. The second question needs further elaboration, as we expect that the answer will depend on the practical model ('conflict', 'bridging' or 'enhancing of detail').

P1 uses 'bridging'-experiments to guide students to understanding the analogy of an 'anchor'-situation to a 'target'-situation. Students initially fail to see that analogy. The analogy between 'anchor' and 'bridge', and between 'bridge' and 'target' should be more obvious. Through reasoning about these analogies, it is hoped they come to realise the analogy between 'anchor' and 'target', which is inconsistent ('dissonance') with their initial description of the 'target'-situation. The 'anchor-target'-analogy will provide the help needed in constructing a new rule for the 'target'-situation.

In this type of practical the sequencing of experiments and questions on interpretations of results is very important. Students need to follow through a number of procedural and mental steps before they can arrive at a situation of 'dissonance' that creates the need for constructing a new rule. In demonstrations, the teacher will be able to give clever guidance to make students immediately aware of inconsistencies in their reasoning, that may go unnoticed for a long time if they work in small groups. Awareness of these inconsistencies is the main condition to effect 'dissonance'. Therefore, demonstration practicals using 'conceptual bridges' are expected to be more effective in creating cognitive change in students, than SGP using the same 'conceptual bridges'.

Table 1. Expected comparison of effectiveness of teaching modes for each practical model.

Teaching aim	Model	Compared effectiveness (expected)
P1. Balance of forces on objects at rest	bridging	DEMO > SGP
P2. Distinguish acceleration from speed	enhancing of detail	DEMO > SGP
P3. Forces on objects in uniform motion and projectiles	conflict	DEMO = SGP

In P2, as P1, a number of steps involving observations and analogous reasoning lead to 'dissonance', discrepancy between ideas expressed initially and the conclusions/observations made later. Resolving the situation of 'dissonance' involves realising that it makes sense to distinguish a quantity from the rate at which it changes. The sequencing of the experiments and consistence of reasoning are as important as in 'bridging'-type practicals. It is expected that in this practical as well, demonstrations are more effective than SGP.

P3 uses 'conceptual conflict': the discrepancy between expectations and observations should be immediately obvious. Resolving dissonance requires little reasoning. It is expected that in this case demonstrations and small group practicals will be equally effective. We summarize these expectations in Table 1.

5 METHODOLOGY

This paragraph consists of four sections. In the first we will describe the sample of students. In the second we will indicate the research method and instruments. The third section will describe the teaching modes in some detail. In the fourth section the content and structure of the practicals is given.

5.1 The sample

The researched practicals were taught in 6 PESC groups of 32 students each. All groups were composed on the basis of O-level examination marks in mathematics and the sciences, to contain as much as possible equal numbers of academically 'weak', 'average' and 'strong' students. The 6 groups (192 students) were selected from the total of 14 groups (420 students) of PESC 1993. The choice was based on timetable considerations, convenient to the participating teachers.

Students selected for PESC are academically the strongest secondary school students in maths and science of Botswana (Cantrell et al., 1993). In selections for PESC 1993, various subject combinations at O-level are allowed, but all students must have done mathematics. Around 80% of all students entering PESC have done a combination including physics, chemistry and biology as separate science subjects. Although these students completed O-levels with good marks in the sciences, their practical skills are not considered to be proficient. At secondary school, practicals are often mainly taught as training exercises for the practical part of the exam (Cantrell et al., 1993).

5.2 Research method and instruments

Of the 6 groups that were involved in research, each practical was to be taught in 3 groups as a teacher demonstrations, and in 3 groups as SGP. In demonstration and SGP the same teaching materials, the same experimental set-up and the same amount of time were used. One physics teacher and one of us (PD) taught 2 groups each, using demonstration in 1 group and SGP in the other. Two more PESC teachers participated, teaching 1 group each, either as demonstration or SGP. The three PESC teachers and the researcher had taught in PESC for at least 4 years.

Each practical starts with 2 or 3 short questions, predicting the experimental results or describing situations similar to those in the experiments. These 'survey' questions serve to elicit student ideas pertaining to the practical. We will report on student answers to 'survey' questions.

During the practicals, students used worksheets containing instructions and questions. Copies were made of students' answers given in the worksheets, to obtain a qualitative idea of how well students were able to execute the practicals.

1 or 2 days after each practical students answered 'intermediate tests' (abbreviated "IT") of 4 to 11 questions, specific for each of the practicals. The results of these IT's will be discussed quantitatively.

Classroom observations were carried out for each practical in the 4 classes not taught by the researcher. Each practical was discussed by interview or questionnaire, with the teachers.

At least one week after each lab, interviews were carried out with 3 or 4 students, either in pairs or single. These interviews were audio recorded. During the interviews, the set-up used in the practical could be used. Students were selected for interviews on the basis of the answers they gave to pre-course test, survey and IT. It was attempted to select students giving answers that were typical for many students, i.e. to select average students. During the interviews, enlarged diagrams of survey and IT questions were used to ask students to answer these questions again and try to explain their present and previous answers. This resulted in a total of 9 interviews. We will report on the qualitative analysis of the 4 interviews for which transcripts are now available.

Pre and post course tests were administered, but could not yet be analyzed. Hence we will be unable to report on retention effects at this time.

5.3 Teaching modes

Two main aspects need to be taken into account when comparing demonstration and SGP: the way in which guidance and stimulus is provided by the teacher, and the group-size in the activities occurring during the practicals.

We use the elements in the process of constructing understanding (as in section 2) in distinguishing teacher guidance activities:

- *Predictions by students*.

The teacher elicits, without being judgmental, that the students appear to use quite different ideas at the start of each lab. This is expected to provide stimulus to investigate, to find out 'who is right'.

- *Observations and creating dissonance*.

The teacher tries to ensure that discrepancies between expectations and observations are realised. If this fails, the student will not be able to experience 'dissonance'.

- *Formulating a (tentative) conclusion*.

The teacher may have to assist the student in formulating and adopting, if only tentatively, a conclusion to resolve dissonance, if the students themselves fail to do so.

- *Testing and evaluating the conclusion*.

After testing the conclusion the teacher and students may engage in a discussion on the new rule (*negotiation of meanings*). This provides an evaluation of the ways in which the new rule (and the original ideas) was tested. True 'negotiation' occurs only if the teacher structures the discussion to allow a free exchange of views.

- *Generalisation and application of the rule*.

The teacher guides a discussion on student answers to questions on generalisation and application of the new rule. This may again involve negotiation of meanings, and provide the student with the possibility of verifying and evaluating her answers.

In describing the group size involved in several activities, we can distinguish individual, small group (3-4 students) and whole class (app. 30 students) activities. 'Predictions' and 'generalisations', both in demonstration practicals and SGP, are first done individually, and then compared in the whole class. Differences between SGP and demonstration (DEMO) are found in the remaining activities, and summarised in table 2.

Table 2. Brief description of class and small group activities in teacher demonstrations and SGP.

Mode	Activities by the whole class	Activities in small groups
SGP	- comparison, discussion, evaluation **after** small group conclusions / interpretations	- collect data, observe results - interpretation and conclusions
DEMO	- comparison, discussion, evaluation **during** the experiment, - all observe the same events, obtain identical data	

In demonstrations, the teacher was to execute the experiment with the group as a whole, and to discuss the phenomena with the students. Through ensuring agreement on what is seen, and by asking the right questions, the teacher may provide ample guidance throughout the process and be in strong control. The steps of creating awareness of 'dissonance', formulating and evaluating the new rule thus become one fluent whole for the student.

In SGP, the students would first execute the experiments, interpret the results, formulate and discuss a tentative conclusion in small groups. That discussion provided a first evaluation of the conclusion. At that stage, the teacher provided guidance to small groups, and teacher control was not strong. Before generalising the conclusion, it was dicussed in the whole class. During this evaluation teacher control in SGP will be less than in demonstrations: it will be more difficult to refer to observations (as those probably differ per group), repeat observations or formulate appropriate (teacher) questions. In demonstrations, more teacher control and guidance may be expected, concerning the establishment of awareness of 'dissonance', formulating a tentative conclusion, and evaluating the conclusion, than in SGP.

5.4 Common phased structure of the practicals

The structure of the 'concept labs' can be characterised by 4 phases, linked to the elements in the process of constructing understanding, that can be recognised in each of the practicals:

Phase 1: Express initial ideas and/or predictions. (Survey of ideas)
Phase 2: Observe the phenomenon, interpret the results, formulate a conclusion.
Phase 3: Test the conclusion.
Phase 4: Generalise and apply the conclusion.

Note: Separating 'obtaining observations' and 'drawing conclusions' was useful in describing the practical models, but can often not be distinguished in terms of classroom activities. Therefore they are combined in phase 2.

5.5 P1. Balance of forces working on objects at rest

This practical aims to address ideas concerning induced forces on objects at rest. It uses the 'anchor-bridge'-model. The situation of an object on a non-deforming support is considered to be an 'anchor'- situation. This assumption is tested in the pre course test. The practical is carried out in 1 session of 100 minutes.

Phase 1. At the start of this practical, students are asked to draw and name all forces, and to compare the magnitudes of forces pointing in opposite directions, working on an object on a bending support or an object that remains at rest while being pulled.

Phase 2. Students do a number of 'bridging' experiments; objects are hung from a spring, the spring is extended by hand, a ruler is suspended horizontally and loads are put on top of it. These experiments aim to guide to the understanding (first target), that the deformation of the support explains how the supporting force arises, and that the supporting force balances the weight of the object. Links to the 'anchor'-situation are established by using extremely small loads that cause deformation that must exist but is not visible.

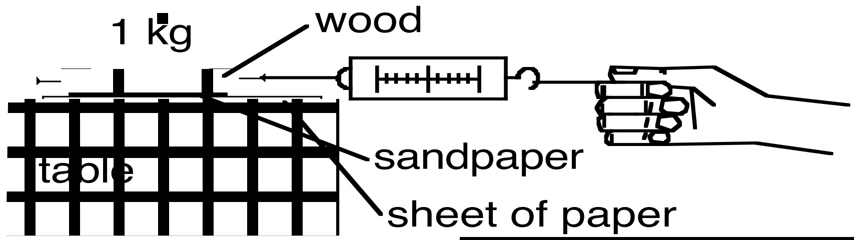


Figure 1. Verify: object remains at rest when pulled.

Phase 3. Students answer the 'survey' questions about supported objects once again.

Phase 4. The conclusion is generalised and applied in an experiment; see figures 1-3. In each figure, the same object is pulled to the right, with the same force, and remains at rest. In figure 1, friction with the table prevents motion. In figure 2, $F_{\text{to the left}}$ is determined that is needed to prevent motion. Students are to realise that this is a way to find the magnitude of the friction in figure 1.

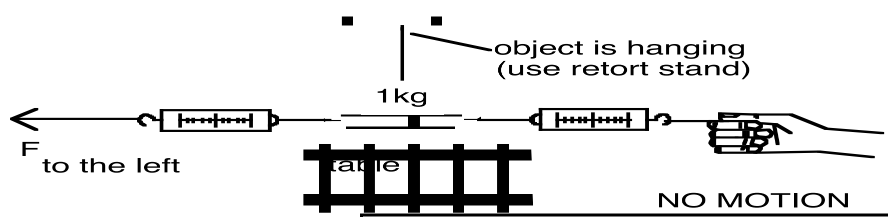


Figure 2. Compare forces on object at rest.

In figure 3 the object is placed on a brush. The hairs of the brush will bend as a force is exerted, and more so if the force is increased. This leads to the second target: the deformations are responsible for frictional forces, and explain how friction adapts to the exerted force. Friction balances the exerted force if the object remains at rest.

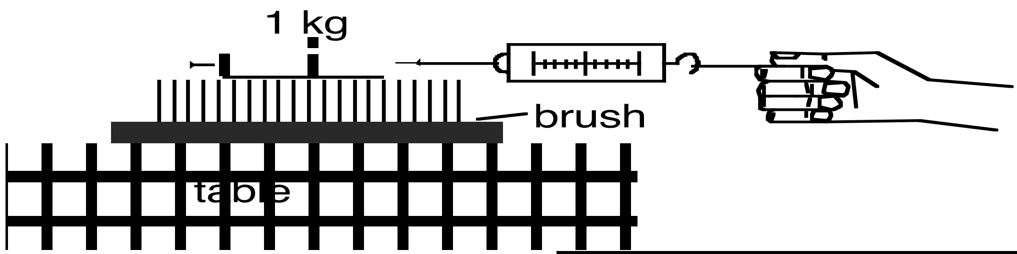


Figure 3. What happens to the hairs of the brush when you pull?

A hand-out text, distributed at the end of the lab, uses a simplified model of molecular bonds to explain the mechanism of deformation leading to these elastic forces (normal force and friction) a bit further. The name 'induced forces' is also explained. In conclusion students answer the remainder of the survey and compare with the answer given previously.

The experiments in phase 2 closely resemble those reported by Clement (1987), except that their role has changed. What we call 'anchor', 'bridge' and 'target' experiments are for him 'target', 'anchor' and 'bridge', respectively. Note however that the students that this practical aims at are less naive than Clement's, as they do identify the supporting force. The practical aims to show the **balance** of forces, which implies some quantitative observations in the 'bridge'. Thus, depending on the state of knowledge of the students and the idea that an experiment illustrates, it may fulfil quite different roles in different practicals.

5.6 P2. Distinguish acceleration from speed as aspects of motion

The practical was based on ideas presented by Epstein (1979). It attempts to clarify the distinction between acceleration and speed. It uses the 'enhancing of detail'- model and takes 1 session of 100 minutes.

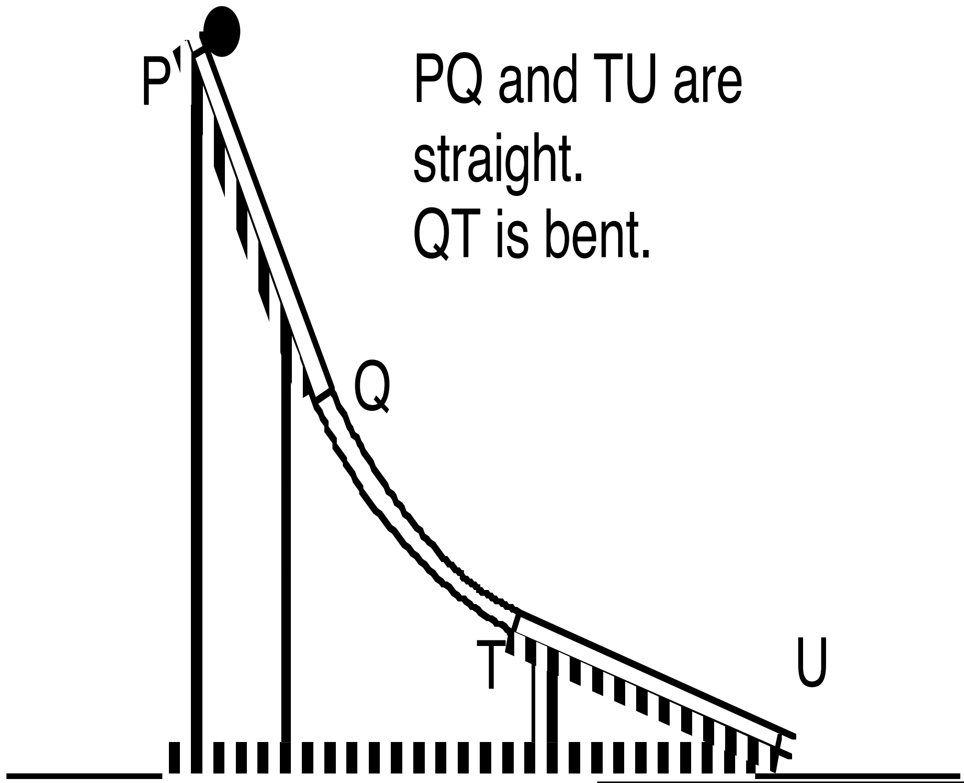


Figure 4. Ball on a rail of varying steepness.

Phase 1. At the start of the practical, students predict whether speed and acceleration will increase, decrease, be constant or zero for several frictionless motions. In all cases the speed increases, while the acceleration is either constant or decreases (according to physics).

Phase 2. Experiments are conducted about the speed of a ball rolling down straight rails at various inclines. Rule aimed for: the speed of a ball increases, if it rolls over a rail that has a downward slope. Students are then asked what they observe to happen to the speed of a ball rolling down the rail shown in figure 4. Most will opt for one of the following:
- On PQ it increases, on QT it decreases, on TU it increases.
- It increases all the way.
- It is constant on PQ, decreases on QT and is constant again on TU.
(The experiment actually aims to help students clarify for themselves, what they mean by 'it'.)
This is followed by experiments that now focus on the *amount of increase* in

speed on the same straight downward rails used in the first series of experiments. The definition of acceleration is brought into play, and students are asked to pay attention to the role of the steepness of the rail. Speed and acceleration of the ball on the slope of figure 4 are once more considered. It is hoped that students come to realise: the acceleration of an object can decrease, even while its speed continues to increase. (The acceleration depends only on the steepness of the rail.) This tentative conclusion is quite counter-intuitive, as can be witnessed from student statements during and after the lab.

Phase 3. Students are asked to answer a few simple numerical exercises involving applying the definition of acceleration. These confirm the tentative conclusion, and may make it more plausible. Students are then asked to return to the survey and answer the first two questions again.

Phase 4. The situation is generalised to free fall downwards (a 'vertical rail'). The corresponding survey question is answered again, while comparison with the initial answers is made.

Most students show correct initial ideas about the speed of an object moving down a straight rail. The increase of the speed on a rail of decreasing steepness hopefully becomes intelligible through the intermediate step of considering straight rails with different slopes. Classroom observations and student statements show, that it is extremely likely that students will experience 'dissonance' or 'cognitive conflict' as a consequence of the discussion of the speed of the ball on the rail of changing steepness.

The discussion of acceleration cannot use analogical reasoning. It attempts to provide a model, using steepness, to show that speed and acceleration are **not** analogous. It attempts to clarify the distinction through a more precise description of the occurring events than was originally given.

Students have many more problems with the concept of 'acceleration' (vector character, x-t, v-t and a-t graphs, deceleration as a form of acceleration). This practical cannot address these problems, it merely attempts to create awareness among students, that acceleration and speed are distinctly different, and to provide a preliminary aid ('steepness') in clarifying that distinction. (Preliminary, as in good time it will be expanded to include Newton's second law of motion.) It is hoped that this awareness makes the subsequent, formal teaching of acceleration more successful in terms of conceptual development.

5.7 P3. Forces on objects in uniform motion and projectiles

This practical addresses 'impetus'-ideas of force. It uses a 'conflict' model. It consists of a session of 100 minutes plus one of 50 minutes.

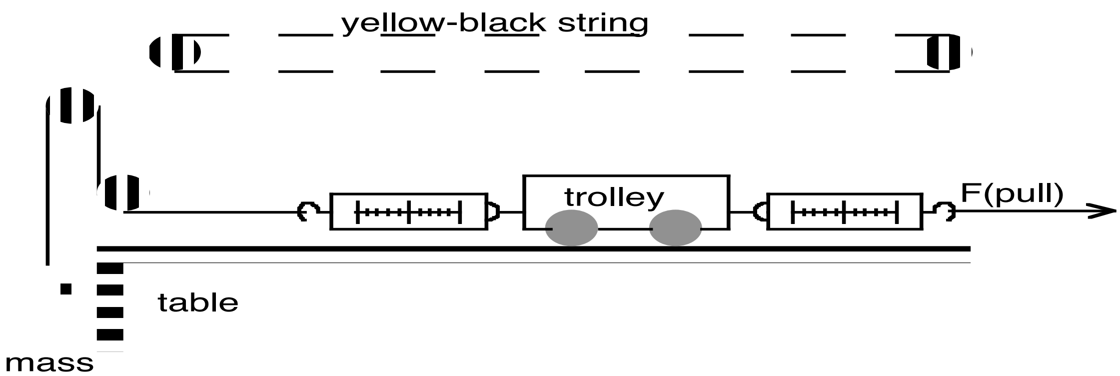


Figure 5. Illustration of Practical 3.

Phase 1. Students are asked to draw and name the forces working on a projectile. They also predict the outcomes of the experiment (figure 5). A trolley is pulled forward at constant velocity. A backward force is exerted on the trolley by the hanging mass. Students predict how the forward force compares with the backward one, for speed zero, 'low', 'medium' and 'high'. ('High' is about 2 m s^{-1}.) They predict whether the forward and backward forces change if a higher speed is maintained. As a sufficiently big hanging mass is chosen, friction can be neglected. The constant speed of the trolley is achieved by pulling it along with the rotating 'yellow-black' string above the set-up, that is propelled by an electromotor and gearbox.

Phase 2. The experiment is carried out. The vast majority of students conclude, that the forward and backward force are equal, balance each other, and are independent of the speed.

Phase 3. As students write down their conclusions, a comparison is made with the predictions. Linking to prior knowledge is difficult. Instead, students are asked to compare their conclusion with the formal wording in a textbook of Newton's First Law.

Phase 4. In the second session, the situation is generalised to frictionless horizontal motion. Most students already believe that the speed of an object is constant in that situation. A short demonstration experiment is available to confirm this.

The line of reasoning suggested is: if the backward force is zero newton, and the speed still constant, then the experimental results suggest that the forward force is also zero newton. Thus there is no 'impetus'-force. Consequently, if there is no propulsion, even if there is friction, the forward force on a projectile is still zero newton, there is no 'impetus'-force. Students are made to contemplate these issues, and suggest other physical quantities that the moving object does possess, through a paper posing 11 questions on two situations. Finally, students answer the question about the ball flying through the air again, and compare with their earlier answer.

'Dissonance' may arise when students find observations that disagree with their predictions. Classroom observation suggests, that many students experience 'dissonance' again later, when they come to realise where this line of reasoning is leading them.

6 RESULTS

We will start this section by giving some preliminary quantitative results regarding each practical. Then we will compare demonstrations with SGP for each practical. Thereafter we discuss the execution of the practicals and the influence of the teacher. Finally we use results from student interviews to illustrate the limitations of measuring student understanding through large-scale tests, and to provide further qualitative information on the effect of the practicals on student ideas.

6.1 Quantitative results

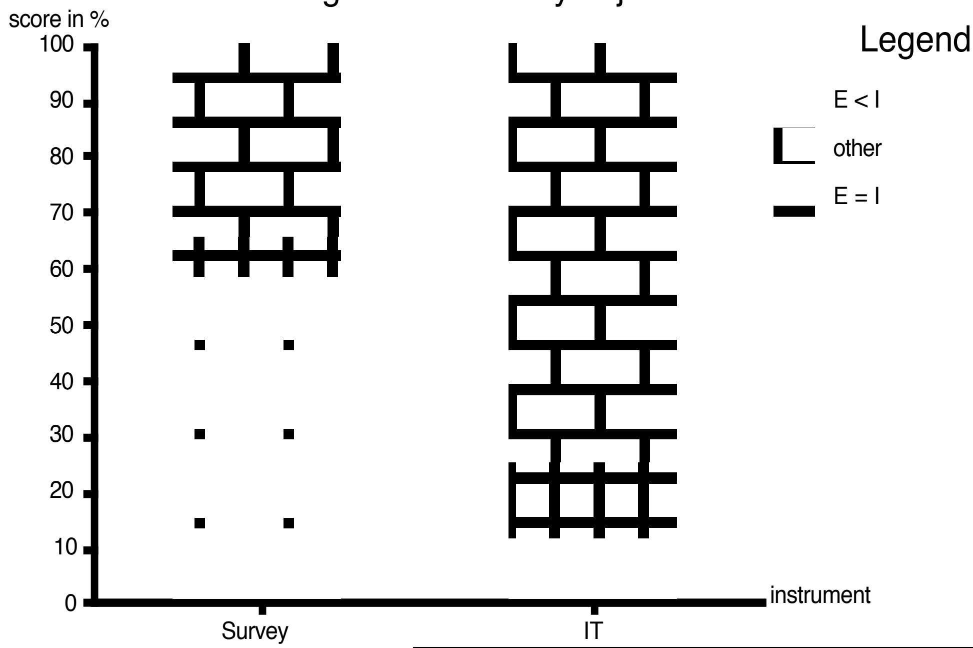
Results reported in this section are based on student answers to 2 or 3 short questions answered at the start of each lab ('Survey') and on answers to a test of 4 to 11 questions answered one or two days after the lab (intermediate test, 'IT'). In this section, we lump together results from all groups, not separating for demonstration or SGP. The results show whether the practicals have an effect on the student body at large in terms of test-questions that call for the use of the incorrect student idea aimed for in the practical.

We will report the results through bar charts pertaining to the key intuitive student idea aimed at in each of the practicals. Each bar consists of three sections. In all charts, the top section shows the percentage of students giving the physically correct answer. The bottom section shows the percentage of students giving an answer that follows from the key intuitive student idea. The central section is the percentage of students giving other answers.

P1. Balance of forces working on objects at rest

We present results for the idea regarding friction: if a force is exerted on an object, but it remains at rest, then the exerted force (pull) is less than the force preventing motion (friction). According to physics, these forces must be equal in magnitude, if the object remains stationary.

Graph 1. Comparison of exerted (E) and induced (I) force working on a stationary object.



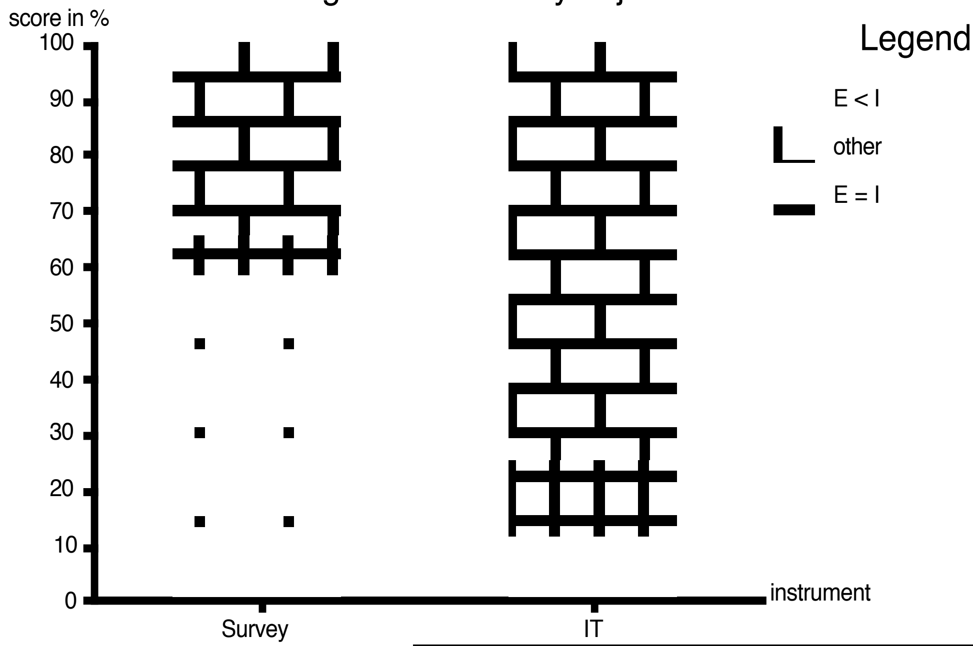
In the survey at the start of the lab, a Graph 1. figure is presented of a boy pulling a rope that is attached to a log lying on the ground. The log remains stationary. Students are asked to draw and label all forces working on the log. If they find a force directed opposite to the pulling force exerted by the boy, they are asked to compare the magnitudes of the two forces.

The question is repeated for the case when two boys are pulling, while the log remains stationary. In a similar fashion, the intermediate test (IT) after the lab asks to compare horizontal forces on a car stuck in sand, that is pushed by two persons but remains at rest. Similar for a boy engaged in a tug-of-war, that stays at rest.

In graph 1, the results on the two questions in each test have been averaged. For the survey: N=181, for IT: N=172. The graph shows that the number of students using the intuitive idea is reduced from 58% before to 11% after the lab. The number of correct answers increases from 35% to 75%.

P2. Distinguish acceleration from speed as aspects of motion

Graph 1. Comparison of exerted (E) and induced (I) force working on a stationary object.



Graph 2.

In the lab a situation is studied where the speed increases while the acceleration decreases. Graph 2 is about test questions where the correct answer is: the speed increases and the acceleration is *constant*. In the survey students are asked whether the speed of a trolley, moving down a straight runway without friction, increases, decreases or is constant. The same is asked for the acceleration. The situation is presented in a drawing. It is repeated for a cup that falls down from a table. In the IT, these questions are asked for a bicycle moving down a slope of constant steepness and a brick falling off a building. The frequencies of answers to the two questions for each test were averaged to produce graph 2. Correct answers increase from 45% to 63%.

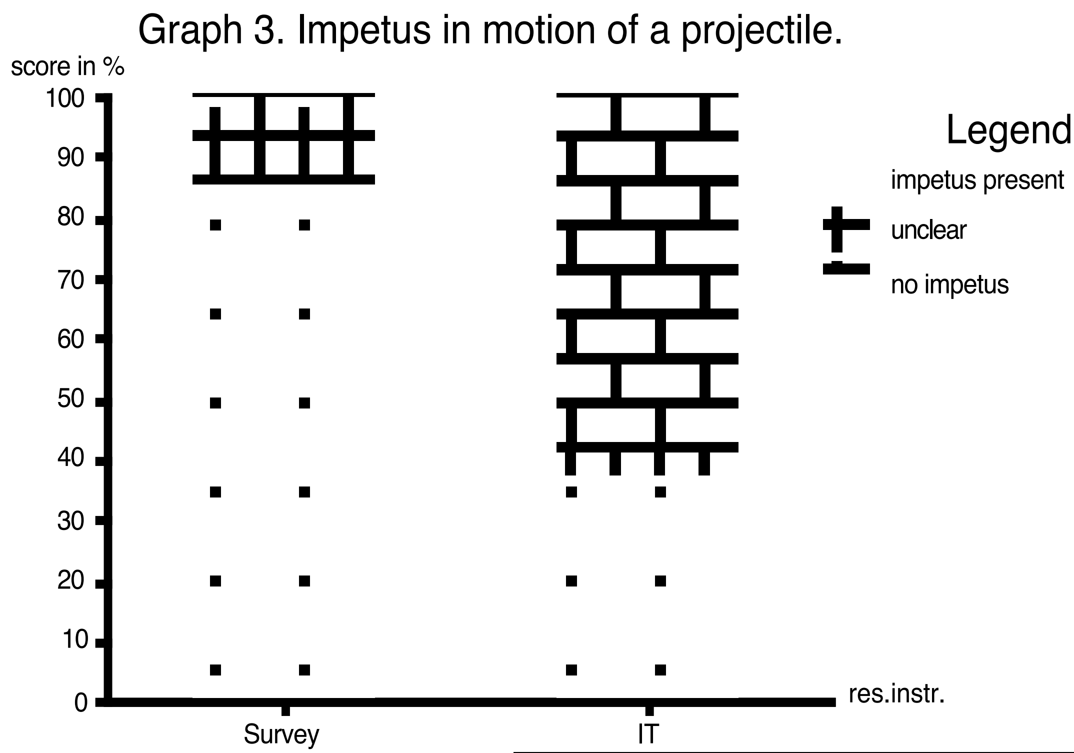
At the start, 38% of the students state that a and v change in the same way. After the practical, 21% of the students still says that. For the survey, N=181. For IT, N=178.

On a question involving the situation studied in the lab (the acceleration is now not constant but decreases) 27% of the students gave the correct answer before the practical. One or two days after the lab, 82% of the students remembered that this was the correct answer.

P3. Forces on objects in uniform motion and projectiles

At the start of the experiment, 50% of the students expect at the start that the forward force will be bigger than the backward force if the speed of the trolley in figure 5 is constant. After the lab, the percentage has dropped to 15% for similarly moving objects.

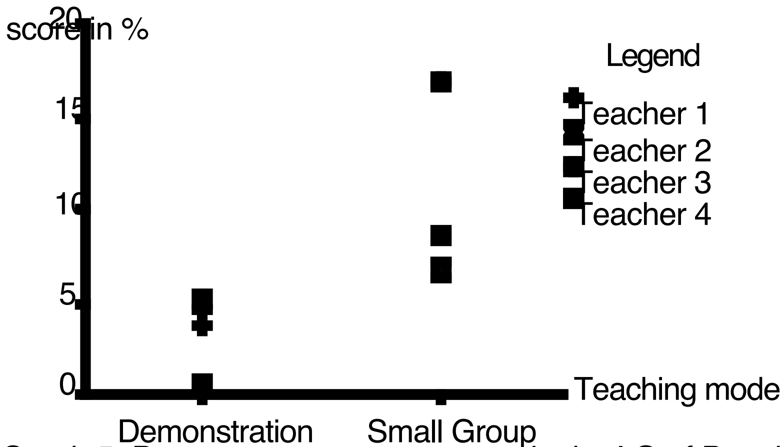
The bar-chart shows results of questions about the presence of an impetus-force on projectiles. At the start of the practical, the use of this idea is tested in one survey question. Students are asked to draw and name all forces working on a soccer-ball that was kicked into the air. A drawing of the situation is given. After the lab in the IT students are asked to draw and name all forces on objects in nine different situations. In 4 of these, no forward force is present according to physics.



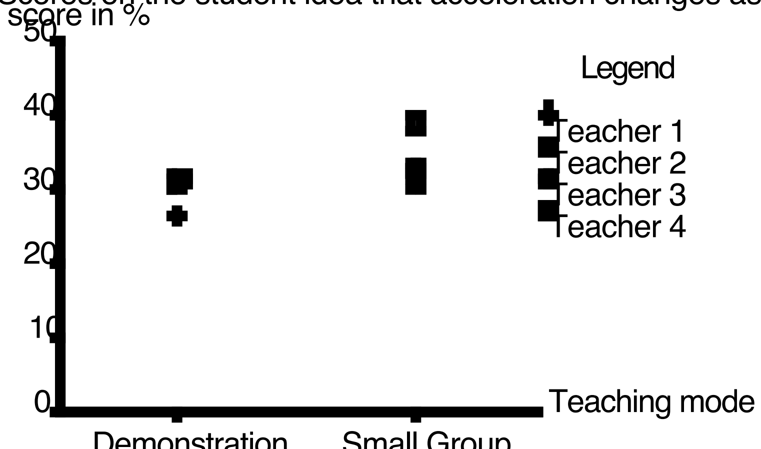
Graph 3.

For the IT-bar in graph 3, averages of frequencies for the 4 questions were taken. Between the 4 questions, frequencies differed less than 4%. The category 'other' answers concerns students that drew an arrow in the direction of motion and called it 'momentum' or 'speed'. At the start, 85% of the students indicated an impetus-type force on the soccer-ball. After the lab, on average 37% of the students still indicate such a force in similar situations.

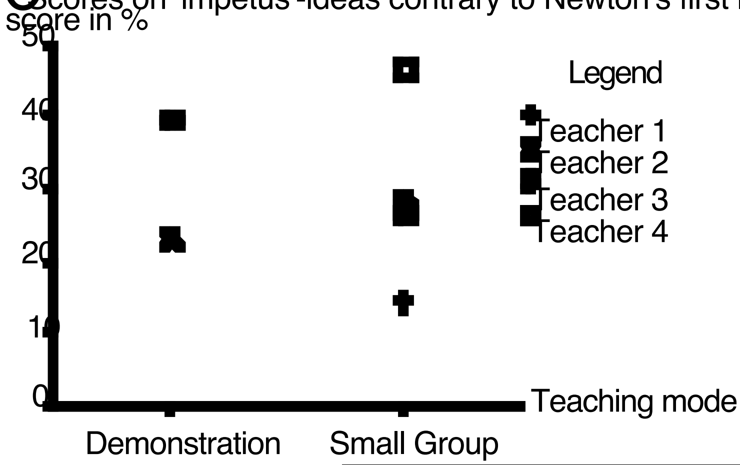
Graph 4. Percentage score per group in the I.Q of Practical 1.
Scores on student ideas Pull < Friction and F(down) > F(up).



Graph 5. Percentage score per group in the I.Q of Practical 2.
Scores on the student idea that acceleration changes as speed.



Graph 6. Percentage score per group in the I.Q of Practical 3.
Scores on 'impetus'-ideas contrary to Newton's first law.



Graph 4.

6.2 Comparison of demonstration with small group practical

In this section we wish to compare the teaching modes of demonstration and small group practical in a quantitative way. Student scores on the intermediate test, written 1 or 2 days after the practical, are used.

In each IT those items were selected, in which the student may use the student ideas aimed for in each of the practicals. Each item is coded 1 if the student uses the expected, incorrect idea, and 0 if the answer is correct or not based on the expected idea.

The item-scores for each student are added to a total score for each IT and converted to a percentage. Graphs 4-6 show the group averages for the IT's of Practicals 1, 2 and 3, respectively. Each plotted point represents a group mean. For each practical, groups receiving demonstrations are given on the left, groups doing small group labs appear on the right. The symbol by which the group mean is plotted represents the teacher for that group.
The scales obtained have Cronbach alpha coefficients of
P1: 0.56 (5 items, 172 cases),
P2: 0.50 (7 items, 173 cases),
P3: 0.70 (7 items, 159 cases).

The graphs suggest, that demonstrations may be more effective in practicals 1 and 2 than small group practicals. Note that the score is higher if **more** students use the incorrect idea after the lab. In practical 3, both modes seem to be equally effective.

To verify whether the observed differences are statistically significant, analysis of variance was executed. This implies comparing means and standard deviations of all demonstration groups with those of all small-group practical groups. Table 3 shows F values and their significance resulting from the ANOVA calculations for each of the practicals. Note that the comparison is based on the answers of students that still use the incorrect student ideas after the practicals.

A similar procedure may be executed based on physically correct answers, rather than answers based on the expected intuitive ideas. The results of this procedure are given as well in table 3, and on the whole appear to confirm the results of the first procedure. This is not obvious: a test often has many items that can be scored correctly or incorrectly, while only a limited number of these items involve the ideas aimed for, as can be seen from the number of items in each scale. The following Cronbach alpha reliabilities were obtained:

P1: $\alpha = 0.52$ (11 items, 147 cases)
P2: $\alpha = 0.62$ (11 items, 173 cases)
P3: $\alpha = 0.61$ (7 items, 159 cases)

A comparison using analysis of variance makes sense only, if initially there is no difference between the groups. At a later stage, this may be verified using pre course test results. At present however, only survey results are available for this check. Due to the low number of items (2 or 3) these are not very reliable. Survey scores on the student ideas aimed for were constructed along the same lines as those for IT's. Only in one case, for Practical 2 when regarding the scores on incorrect ideas, a significant initial difference was found beyond the 0.05 level. An F-ratio of 4.3 was found, with a probability of 4%. In that case the survey score may be used as a covariate in the analysis of variance in the IT-scores. That analysis renders: F = 2.1 (significance of F: 0.15). In other words, initial differences between groups have no influence on the results reported in table 3.

Table 3. Results of analysis of variance, comparing groups taught by demonstration to groups taught in SGP, based on intermediate tests of each practical.

	Analysis based on scores of students using incorrect student ideas		physically correct ideas	
	F-ratio	significance of F	F-ratio	significance of F
Practical 1	8.15	0.005**	4.43	0.037*
Practical 2	2.81	0.10	6.18	0.014*
Practical 3	0.68	0.41	0.06	0.81

**:significant beyond 0.01 level. *:significant beyond 0.05 level.

Comparing the group means and standard deviations, we find that demonstrations are significantly (p=0.05) more effective than small group practicals in teaching students the correct physical concept in Practicals 1 and 2. Demonstrations are significantly (p=0.05) more effective in Practical 1 also in reducing the use of the targeted incorrect student idea. No evidence can be found that in Practical 3, demonstrations or small group practicals are more effective. The differences must be interpreted carefully, as the reliability of the tests is fairly low.

6.3 Influence of the teacher.

*** Preparations before teaching.**

It is assumed in this research that a constructivist approach to teaching is essential in effecting conceptual change among students. It is difficult however to clarify to lecturers what a constructivist approach concretely means in terms of classroom activities, or to have them adopt such an approach in class.

The research reported on here took place in 1993 and was piloted in 1992. In 1992 preparation of teachers was attempted both through the use of role-play with teachers and researcher, and extensive teaching manuals. Neither method influenced subsequent teaching in a satisfactory way. The manuals were too extensive to be of practical use to the teachers, the researcher did not have the impression that his intentions were sufficiently clear to the teachers. The manuals were reduced to one-page schedules, providing a tentative timetable for the various parts within each lab, and the main activities during the lab. These were produced on the basis of trial runs of each lab with 2 students, taught by the researcher. The lecturers indicated that these schedules were useful in preparing for teaching the practical, and that they often referred to them during the practicals. In general the schedules were followed well. The lecturers indicated that the teaching aims and structure of the lab would have been clear enough even without the schedules. However, at times lecturers deviated even in essential aspects from the schedules, omitting e.g. class discussions of results.

*** Opinions of lecturers about the practicals.**

After each practical, through interviews or questionnaires, the lecturers were asked for their opinions about it. In general they indicated to be satisfied with content, structure and time available in each practical. Lecturers were further asked whether they preferred practicals that aim at concept construction or practicals that confirm theory that has already been discussed in class. They were also asked for their preference regarding demonstrations and small group labs. One lecturer clearly preferred small group practicals. In general however, the lecturers indicated to prefer to use as much variation in teaching approach as possible, rather than preferring one method over the other. For the topics of the researched practicals, lecturers agreed with the 'concept construction'-approach.

*** Were the practicals taught as intended?**

On the basis of classroom observations, it was attempted to determine the extent to which teachers were able to teach the practicals as was intended by the researcher. Whether failure to do so actually has any influence on the effectiveness of the practical is hard to prove, as many other uncontrolled factors may also contribute. We may however consider whether the comments based on classroom observations coincide with the results as given in Graphs 4-6. We will limit ourselves to the following qualitative observations on the basis of that comparison. There are indications that students benefit from discussing and evaluating their own conclusions with each other and the teacher. This 'negotiation of meanings' works better if the students have more freedom in deciding what to discuss. Limiting the discussion to the student ideas that the practicals aim at does not seem to be beneficial. The teachers however sometimes find it difficult to conduct a free 'negotiation', fail to provide sufficient stimulation for it to occur. In cases where a teacher failed to 'manage' the intended 'negotiation', he mostly reverted to giving his own explanation as best he could. In case the practical was otherwise well conducted, this had no clearly observable adverse effects on student performance. Only if the teacher fails on several counts to follow the intentions and structure of the practical, clear negative effects on group performance are observed. Note that PESC students have completed 5 years of secondary school, where most activities are strongly teacher framed and discussions about student ideas rare. Students may need more experience and time before they are able to make proper use of student-based activities and class discussions of their own ideas and opinions.

***	The researcher as teacher.**

One of the researchers (PD) participated in teaching the researched practicals. In graphs 4-6, he is 'teacher 2', represented by 'X'. No classroom observations were carried out during the researcher's teaching. Inspection of the graphs shows that results obtained by groups taught by the researcher were not very different from those obtained by other groups. The fact that he was better informed about the intentions and content of the practicals did not result in an extreme performance of the groups taught by him. Therefore, there is no indication that the results obtained in those groups need to be treated separately.

6.4 The quality of student understanding gained in the practicals

Tests administered to large numbers of students cannot probe deeply into the quality of their understanding. It would be difficult to design tests that elicit why the student has decided to use, after the practical, another rule in describing situations, how this rule fits in with other ideas that student has or whether the student can defend the rule against alternative rules. Interviews are more suitable to this end. Therefore interviews were conducted with 3 or 4 students for each practical. These interviews occurred a week or longer after the practical was carried out. Students were selected on the basis of the answers they gave in the survey at the start of each lab and in the IT written some days after each lab. It was attempted to select students answering in a way typical for a large group of students.

Students were interviewed in pairs or as single individuals. In case a pair was interviewed, it was attempted to select students with opposing views. Students were informed that the interviews would in no way be used for assessing their performance. It was explained that the researcher was not interested in whether their answers were right or wrong, but in their reasons for giving those answers. Audio-recordings were made, while students were told that only the researcher would be allowed to listen to these. We will not use students' names when quoting from interviews.

Each interview was conducted on the basis of the (enlarged) diagrams of situations that had been presented to students in worksheets and tests. During each interview, the lab equipment used in the practical was on the table. Occasionally, experiments from the practical were briefly repeated if the need arose.

It will not be possible to give a thorough picture of the quality of students' understanding. Rather, we will pose a number of questions about that quality and give a tentative answer, illustrated by quotes from interviews.

* Do students understand what the practicals are about?

Each interview was started by asking students if they remembered what the practical was about and what its main conclusions were. The following quote is from an interview about P2, with B (a girl) and P (a boy). I is the interviewer.

> *I: ...What was it about? Could you try to summarize it in one sentence or is that a difficult question?*
>
> *P: I think that.. when.. acceleration increases.. it does not mean that, er I mean that when velocity increases it does not mean that acceleration will also increase.*
>
> *I: Aha..*
>
> *P: So, acceleration may decrease, even if velocity increases. That's what I learned.*
>
> *I: Ok. Same for you? Do you have anything to add to that or not?*
>
> *B: Yeah, and the acceleration, the velocity, er, the velocity* ***down*** *the slope increases. That's what I learned. And that acceleration depends on the steepness of the slope.*

Without exception students were able to describe the experiments and conclusions. In case the 'new' rule was also generalised to situations not experimentally studied, they were not always able to formulate that generalisation.

* Can students be provoked into using their original, intuitive idea again?

The interviews show quite a few instances where students tend to reinvoke the ideas that the practicals aimed at, for various reasons. We will illustrate two.

Limited transfer

In P2, one of the results is that the acceleration of an object moving down a straight slope is constant. This is generalised to free downward falling objects. In the interview already quoted with B and P, B indeed stated this, for the case of a brick falling off a building.

Later a ball thrown up in the air is discussed. In the IT, B answered that the acceleration increases during the upward motion. She spontaneously introduces dynamic aspects in her explanation, that are at that time not yet discussed in the course:

B: I thought, because that person introduces a force. It actually drives the ball faster, upwards. That's how I thought.

I: So then, after he let's go of the ball, there's still that force?

B: Yeah, that's what I thought, yes.

B apparently does not relate acceleration and velocity here, but acceleration and impetus force. She does not transfer the results of Practical 2 to the situation of the thrown ball. At the top, the acceleration is zero, she says. Then:

I: It's falling down. What happens to the acceleration?

B: It increases, as it goes down.

I: It increases. Do you agree?

B: NO!! It's constant!

P: Yeah, I think it's constant.

B: Oh god, it's constant.

B almost immediately realised she was reinvoking the 'old' idea. In the practical, an object that falls was discussed. For B, transfer has taken place to the situation of downward fall that occurs as part of the motion of a thrown object. The new rule is however clearly not deeply rooted. Unfortunately the interview does not reveal her reasons for being convinced that the acceleration is constant.

Conflicting knowledge from everyday experience

In an interview with student M (a boy) about P3, M first recalled that the force forward, required to keep the trolley in the experiment at a constant speed, was of the same magnitude at all speeds. The interviewer then attempts to probe M's understanding of real life situations, where friction usually is bigger at higher speeds.

I: Do you know how to ride a bicycle?

M: A bicycle, yes sir.

I: So.. then you probably know that if you want to..

M: move faster..

I: move at a fast speed, you have to push harder than at a low speed.

M: Ok.

I: It doesn't seem to agree with this, with this experiment. Could *you explain?*

M: Yeah, well, that, maybe that was the error of reading the springs. And then.. otherwise it means my view is not very correct. Observations were not very correct.

Rather than trying to match the new rule with everyday experience, M is prepared to abandon it on the basis of experimental error. Of course his reaction is understandable, we merely try to illustrate how feebly the new rule is anchored.

*** Can students rationally defend the correct new rule against the old intuitive idea?**

In the interview just quoted, M says there is no forward force on a projectile. The interviewer continues by asking what, according to M, keeps the motion going. M says it is inertia, and gives a correct definition, in his own words. The interviewer then asks why it is correct to say inertia keeps it going, and wrong to say it is a force.

M: Yeah.. mmm.. I can't answer that one.

I: You can't answer that one. But you have answered it.

[The interviewer meant: during the practical, you answered it.]

M: I have?

In the next part of the interview, the various steps of the practical, generalising from the observations to the new rule (no impetus), were discussed. M recalled each step, but did not connect the steps. He also did not recall reasons from a discussion with his teacher after the practical had finished, that had finally convinced him not to indicate an impetus force.

By asking students what result in the practical made them change their mind, or to defend the new rule in favour of the old one, it was attempted to find back traces of the process of 'construction of new understanding'. In most interviews, a lack of rational reasons surfaced when students were asked to explain why the newly adopted explanation was better than the old one. It is too simple to say that these students just adopted what they thought their teacher wanted them to think. If the 'new' knowledge was really that shallow, it would become difficult to explain how, albeit limited, transfer of knowledge to related situations, as verified in a number of intermediate test questions, could occur. Statements of students further indicate that most of them have the strong feeling of having learned something new in the practicals.

Apparently, students do engage in the process of individually constructing new understanding. They are even aware that something has happened. They are however not able to recall the details of this process. It is very difficult to find back traces of the construction process in interviews.

*** Interference from other intuitive, incorrect ideas**

The new understanding gained in the practicals needs to find a place within the existing body of knowledge of the student. Things may go wrong in that process, as already existing ideas interfere with the newly gained ones. We give one example. In an interview about P3 with G and A (both boys), G defends his opinion that there must be a forward force on a moving projectile. First he says:

> *G: We have a forward force which is the force due to the motion of the ball. Cause the ball is moving forward so there is a force acting on it... forward.*

The other student, A, denies the existence of this force. Therefore G argues:

> *G: Forces always come in pairs.*
> *I: Forces come in pairs.*
> *G: Yeah. I mean.. it's.. pairs, they work in opposite directions. So if you have a force acting backwards which is the force of friction, then there must be an opposite force which is working in the opposite direction. Yeah. So if there is a friction force acting backwards there must be a forward force. Acting on that in the opposite...*

It is very interesting to see how G defends his 'impetus'-ideas seemingly using an incorrect interpretation of Newton's third law of motion. The interview showed however that the rule he mentions for him has no relation to 'action' and 'reaction', but is more a kind of slogan.

*** Final remarks**

When chatting to some students out of class, one of them remarked, that he liked practicals, especially the concept labs, because he had the feeling he really learnt something new. However, he found them very difficult and confusing. He explained that at secondary school he had always thought that physics is 'just common sense', that you can understand it by just thinking straight. The practicals made him realise that physics and common sense were not quite the same at all. The statements of this student show remarkable insight. Indeed, in common sense thinking, what is the problem, if we say a car is too heavy to be pushed away by a person, hence the force preventing motion is bigger than the pushing force? Why should we make a careful distinction between speed and acceleration, if that has no clear applications? What difference does it make, whether we say that the motion of an object continues due to its momentum, inertia or an impetus force? These practicals attempt to show that in physics, all these distinctions do indeed make sense. It is important to realise that for students, however, all these distinctions contradict common sense. The fact that the greater precision in language and thinking is in reality not so much a contradiction as an enrichment of common sense ideas is not trivial and needs to be addressed during teaching.

It is not surprising that the understanding of concepts gained in the practicals is not deeply rooted, may even be misunderstood and cannot be defended very well. It would have been more surprising if students, on the basis of 350 minutes of teaching were prepared to abandon elements in a, for them coherent, body of knowledge built up over many years.

7 CONCLUSIONS

In this research we set out to determine in the first place, whether practical work can contribute to students' understanding of the concept of 'force' in elementary mechanics, on condition that the practicals (1) are 'aim-specific' and (2) are designed to stimulate the process of construction of understanding by students. Such a positive contribution of practical work to improved understanding ought to appear in a reduction of the use of intuitive, incorrect ideas and an increase in the use of scientifically acceptable ideas regarding 'force'.

Three practicals were subject to research, each addressing different aspects of the concept of 'force'. The effects of each practical were determined in various ways. On the basis of test questions, answered by about 180 students at the start of each practical, and some days after it, it was established that all practicals had considerable cognitive effects in a positive

sense.
After P1, the percentage of students giving an answer pertaining to the incorrect intuitive idea aimed for dropped by 47%. The percentage of students answering correctly according to physics increased by 40%. For P2, the percentage of students answering in agreement with the expected incorrect intuitive idea reduces by 17% after the lab, in key questions. 18% more students give correct answers after the practical, in those questions. After P3, the percentage of students answering according to the main intuitive idea aimed for reduces by 48%. For the second idea that the practical aims for, the reduction is 35%. Percentages of students giving scientifically correct answers increase accordingly.

We conclude that practical work that is designed according to the conditions we mentioned can make a positive contribution to student understanding of 'force'.

The second aim of research reported on here, was to compare the teaching mode of teacher demonstration practical with that of small group practical for the three different methods, used to stimulate the process of constructing new knowledge by students, as applied in the practicals. It was assumed, that teacher guidance will be more accurate and precise in properly conducted demonstrations than in good SGPs, and expected, that students need teacher guidance more as reasoning becomes more important.

On that basis, it was expected that demonstrations are more effective than SGP in practicals where arriving at a situation of 'dissonance', and resolving of 'dissonance', depend strongly on (ana)logical reasoning by the students. Accordingly, it was expected that demonstrations and SGP will be equally effective if arriving at 'dissonance' and resolving it requires little more than accepting the observations and perceiving the regularity in the data. These expectations were confirmed.

- Groups taught by demonstration performed significantly ($p=0.05$) better than groups taught by SGP in P1 and P2 on the intermediate tests (IT), if the test-scores were based on scientifically correct answers.
- Groups taught by demonstration performed significantly better ($p=0.01$) than groups taught by SGP in P1 on IT, if test-scores were based on the use of the expected intuitive idea.

- For P3, there is no significant difference between groups taught by SGP and by demonstration, whether the test-scores are based on correct answers or the expected intuitive ideas.
The groups taught by demonstration in Practical 2 performed better, on average, than those taught by SGP, if the test-scores were based on the use of the expected intuitive idea. However, the difference was not significant at the 0.05 level, and does not support the expectations.

The conclusions we have drawn so far are preliminary, for two reasons. In the first place, the number of test questions at the start of each practical was necessarily small, resulting in low reliability of these tests. We hope to establish a more reliable description of student ideas prior to the practicals through the pre-course test that is yet to be analyzed. In the second place, retention of the results by a post-course test could not yet be determined, as the test had not yet been written at the time of production of this paper.

The results of the analysis of the tests indicated that on a large scale, student understanding of 'force' had increased substantially. Through interviewing a limited number of students a week or more after each practical, it was attempted to determine the quality of that improved understanding. From the interviews, it may be concluded that students did understand what each practical was about, and that they remembered the conclusions of the practicals.

In situations that are fairly similar to those studied in the practical, the students were able to apply the new knowledge. Transfer of the new knowledge to situations different from those studied did occur, but not for all students, and transfer rapidly decreased for more 'remote' situations.

The newly gained understanding appeared to be not deeply rooted. Students could fairly easily be provoked into using their old ideas again, e.g. by appealing to everyday life experience.
At least one student extended the newly found rule beyond its boundaries of applicability. Another student appeared not to have completed the process of constructing the new knowledge aimed for at the end of the lab, but made his final decision to abandon his old rule several days later. The 'process' can only

be controlled by the teacher and teaching activities to a limited extent. By asking students to compare old and new rules in various ways, it was attempted to find back traces in the students minds of the process of constructing new knowledge. We did not succeed in finding such traces; students are aware of a change, but appeared unable to describe it in detail.

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References

Berg, E. van den, & Giddings, G. (1992) *Laboratory practical work: an alternative view of laboratory teaching*. Monograph of the Science and Mathematics Education Centre, Curtin University of Technology, Western Australia.

Bernstein, B. (1971). On the classification and framing of educational knowledge. In M.F.D. Young (Ed.), *Knowledge and Control*. London: Collier MacMillan.

Brown, D.E. (1992) Using examples and analogies to remediate misconceptions in physics: factors influencing conceptual change. *Journal of Research in Science Teaching*, 29(1), 7-34.

Cantrell, M.A., Kouwenhoven, W., Mokoena, T.T. & Thijs, G.D. (Eds.) (1993). *Bridging School and University. The Pre-Entry Science Course at the University of Botswana*. Amsterdam: VU University Press.

Chinn, C.A., & Brewer, W.F. (1993). The role of anomalous data in knowledge acquisition: a theoretical framework and implications for science instruction. *Review of Educational Research*, 63(1), 1-49.

Clement, J. (1987). Overcoming students' misconceptions in physics: the role of anchoring intuitions and analogical validity. In J.D. Novak (Ed.), *Proceedings of the second international seminar on misconceptions and educational strategies in science and mathematics*, Vol. III (84-97). Ithaca, NY: Cornell University.

Clement, J., Brown, D.E., & Zietsman, A. (1989). Not all preconceptions are misconceptions: finding 'anchoring conceptions' for grounding instruction on students' intuitions. *International Journal of Science Education*, 11(5), 554-565.

Dreyfus, A., Jungwirth, E., & Eliovitch, R. (1989). Overcoming cognitive obstacles: producing relevant and meaningful cognitive conflicts. *Proceedings 2nd Jerusalem convention 'science and mathematics teaching - interaction between research and practice*.' (108-116).

Driver, R. (1989). Students' conceptions and learning of science. *International Journal of Science Education*, 11(5), 481-490.

Driver, R., Guesne, E., & Tiberghien, A. (Eds.) (1985). *Children's ideas in science*. Milton Keynes, Open University Press.

Epstein, L.C. (1979). *Thinking Physics*. San Francisco: Insight Press.

Garrett, R.M., & Roberts, I.F. (1982). Demonstration versus small group practical work in science education. A critical review of studies since 1900. *Studies in Science Education*, 9, 109-146.

Genderen, D. van, (1989). *Mechanica - Onderwijs in Beweging*. Utrecht: W.C.C.

Glasson, G.E. (1989). The effects of hands-on and teacher demonstration laboratory methods on science achievement in relation to reasoning ability and prior knowledge. *Journal of Research in Science Teaching*, 26(2), 121-131.

Gunstone, R.F., & Champagne, A.B. (1991). Promoting conceptual change in the laboratory In E. Hegarty-Hazel (Ed.), *The student laboratory and the science curriculum*. (159-182). London: Routledge.

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

Hodson, D. (1990). A critical look at practical work in school science. *School Science Review*, 70, 33-40.

Hofstein, A., & Lunetta, V.N. (1982) The role of the laboratory in science teaching: neglected aspects of research. *Review of Educational Research*, 52(2), 201-217.

Kahn, M. (1990). Paradigm lost: the importance of practical work in school science from a developing country perspective. *Studies in Science education*, 18, 127-136

Kempa, R.F. (1988). Functions of and approaches to practical work in science. In G.D. Thijs, H.H. Boer, Macfarlane, I.G., & C.J. Stoll (Eds.), *Learning difficulties and teaching strategies in secondary school* *science and mathematics* (147-163) Amsterdam: VU University Press.

Nussbaum, J., & Novick, S. (1982). Alternative frameworks, conceptual conflicts and accommodation: towards a principled teaching strategy. *Instructional Science*, 11, 183-200.

Possner, G.J., Strike, K.A., Hewson, P.W., & Herzog, W.A. (1982). Accommodation of a scientific conception: toward a theory of conceptual change. *Science Education*, 66(2), 211-227.

Rowell, J.A., & Dawson, C.J. (1981). Volume, conservation and instruction: a classroom based solomon four group study of conflict. *Journal of Research in Science Teaching*, 18(6), 533-546.

Smith, U. (1989). *Awareness of student preconceptions in mechanics - possibilities to improve teaching*. Paper presented at Research Symposium 'Educational research in the SADCC region - present and future.' Gaborone: University of Botswana.

Solomon, J. (1988). Learning through experiment. *Studies in Science Education*, 15, 103-108.

Stavy, R. (1991). Using analogy to overcome misconceptions about conservation of matter. *Journal of Research in Science Teaching*, 28(4), 305-313.

Stavy, R., & Cohen, M. (1989). Overcoming students' misconceptions about conservation of matter by conflict training and analogical reasoning. *Proceedings 2nd Jerusalem convention 'science and mathematics teaching - interaction between research and practice'*. (177-185).

Stavy, R., & Berkovitz, B. (1980) Cognitive conflict as a basis for teaching quantitative aspects of the concept of temperature. *Science Education*, 64(5), 679-692.

Thijs, G.D., & Bosch, G.M. (1993). Cognitive effects of science experiments focusing on students' preconceptions of force: a comparison of demonstrations and small group practicals. Accepted for publication by *International Journal of Science Education*.

Thijs, G.D, Dekkers, P., & Smith, U. (1993). *Research into the understanding of the concept of force carried out in developing countries in co-operation with research in the Netherlands*. Paper presented at the International Conference 'Science Education in Developing Countries: from Theory to Practice'. Jerusalem, Israel, January 3-8, 1993.

Treagust, D.F. (1992). Science teachers' use of analogies: observations from classroom practice. *International Journal of Science Education*, 14(4), 413-422.

Woolnough, B., & Allsop, T. (1985) *Practical work in science*. Cambridge: Cambridge University Press.

Woolnough, B. (Ed.) (1991). *Practical Science*. Milton Keynes: Open University Press.