A Contrastive Teaching Strategy

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Contrastive teaching in the framework of constructivism

Since the 1980s the Institute of Physics Education at the University of Bremen has carried out empirical research on students' alternative conceptions in various domains of physics. These studies focused on mechanics (Schecker, 1985), atomic physics (Bethge, 1988), and science philosophy (Meyling, 1990). The theoretical background is explicated in Niedderer & Schecker (1992). Development and trials of new teaching strategies have been closely related to this work. Our aim is to draw conclusions from findings about students' ideas for the creation of better learning environments. Following basic constructivist principles their main feature is to give students the chance to elicit their ideas and express them freely in class before a new science concept is introduced by the teacher. We speak of *contrastive teaching* in a learner-directed approach. The term *contrastive* refers to *contrastive grammar*, a linguistic method for teaching/learning a foreign language. Grammatical features of the target language are introduced by comparing them explicitly with related structures of the mother tongue. The analogy of the mother tongue lies in students' intuitive ideas about scientific phenomena, while the target is the given by scientific views and concepts.

We hypothesize that as long as a student is not aware of his/her intuitive notions, he/she will hardly be able to learn a related scientific concept. Students e.g. believe that 'force' is an easy-to-learn concept because its meaning seems to be obvious from everyday experiences (Schecker, 1985, p. 452). Empirical studies come to opposite results: *Force* is one of the most difficult concepts to learn. A major reason for this is that students thinks it's so simple. It takes a teaching effort to help them notice the differences between intuitive views derived from everyday experiences and the scientific view based on theory-laden observations. The case study in this chapter about a student-oriented unit in mechanics exemplifies how contrastive teaching can contribute.

Some aspects of constructivist teaching

The constructivist view accentuates the student's active role in the learning process. The teacher has to create adequate learning conditions. We want to point out a few aspects of the learning environment that are important for contrastive teaching.

More qualitative physics

Physics instruction has to spend more time on discussing basic concepts like force and energy, heat and temperature, or light and picture. Too much time is wasted by meaningless calculations. It is more important and more demanding for students to describe the content Newton's laws in own sentences (not just words) than to manipulate formulas like $F=m\cdot a$ and $v=a\cdot t$ to calculate the value of quantity n if (n-1) quantities are given.

Handling deviating student results

In contrastive teaching the teacher refrains from immediate corrections of ‘wrong’ answers, from ignoring deviating proposals, or from blocking alternative ways to tackle a physical problem. Otherwise many students tend to give up physics with comments like "I have never understood that stuff." Other students adopt formal language. They use those key terms that are accepted by the teacher as physically sound.

By withholding his/her expert knowledge the teacher stimulates students to explicate their own ideas. Conceptual deficits can thus become obvious. They are often hidden below the surface because teachers and students use the same formal terms. Both speak of 'forces', 'fields' or 'electrons', but the concepts behind these terms may be quite different.

Students ideas about physics teaching

We should not expect students to be enthusiastic about open-ended teaching. Writing a essay about the forces acting on a parachutist is more difficult than calculating the velocity of a lead sphere in a vacuum. That is why some students prefer equation-based tasks to qualitative tasks. Schecker has described this as *formula-orientation* (cf. Schecker, 1985, p.199). Students tend to underestimate the value of exchanging and confronting different physical ideas in physics lessons. We heard comments like "Do we have to tell another story in the next exam?" In many students’ views, physics (teaching) is a matter of definitions and formal operations with quantities.

Appreciating students' ideas

Students have to feel that their results are valued. Creative own thinking has to be awarded by good scores, even if it differs from the accepted theory. But appreciating alternative conceptions as results of engaged work does not mean to give up convincing students of the superior value of scientific concepts for purposes like universal explanation and prediction.

In a contrastive teaching approach the *comparison* stage of accepted scientific theory with alternative student ideas implies chances and risks:

- Guided comparison can show students structural differences between their concept-system and the scientific theory as well as specific differences.
- Confrontation with completely different physical concepts may disappoint students and make them look upon their own efforts as useless.

One way to get out of this dilemma is to bring in historical texts showing parallels between students’ thinking and earlier stages in the development of scientific theory.

A contrastive teaching strategy

Our contrastive teaching strategy was first published in Niedderer & Schecker (1982). This strategy presupposes a certain capability of meta-analysis on the learner’s side and includes epistemological questions. It is mainly meant for the upper secondary level (students aged 16-19). Driver & Oldham (1985) propose a similar strategy for younger students, in which the “elicitation of ideas” and the "input of scientific view" are similar to our stages 3 and 5.

The strategy can be broken up into six stages:

1) Preparation

The preceding teaching process, e.g., conventional teaching with demonstration experiments and teacher-dominated presentation of concepts.

2) Initiation

An open-ended problem is posed. The teacher sketches a broad framework for students activities (e.g., "What does acceleration depend on?", a = f [?,?,?]), offers a set of apparatus for free experiments, or shows an initial experiment without explaining it. The students work out , or questions and hypotheses for own investigations.

3) Performance

They make experiments, calculations, derivations. The results are formulated in their own words. The teacher does not interfere with the students' activities. He acts as a counselor, helps reservedly with technical problems, supervises an organized working process, i.e., keeps the students to write down questions, ideas, intermediate results, findings etc.

4) Discussion of findings

The student groups present their results in a class forum. The teacher makes notes on the blackboard, using the students’ word. The students compare their findings and try to arrive at common conclusions. The teacher challenges the students' ideas by indicating inconsistencies or suggesting additional experiments. The students defend their notions, perhaps modify them slightly. This phase usually does *not* immediately change students’ ideas.

5) Comparison with scientific theory

The teacher brings in the scientific explanation (concepts, principles, law) as an *alternative view* to the students' ideas — not as 'the truth'. It is compared with the students' ideas from the preceding phase. Commonalties and differences are made explicit. The teacher shows advantages of scientific theory for universal application and precise predictions in a controllable setting. Intuitive conceptions are described as more figurative and better suited for everyday communication about specific single events

6) Reflection

The students look back on ways and difficulties of their problem finding and solving processes. Methodological and epistemological issues are considered. Findings from the philosophy of science about the different structures of everyday-life thinking and scientific thinking can help to notice and accept the differences.

Examples for the application of this strategy are given in Niedderer & Schecker (1982), Schecker (1985), and Niedderer (1987). Contrastive teaching can last from a few minutes to several weeks, as in the example below. An actual unit does not always include all six stages. A short unit can consist of just a free-hand demonstration experiment for which the students write down their observations and questions before any explanations are given by the teacher. Contrastive teaching is not meant to be the overall strategy used in a class. Longer units like the one described in our case study should take place once or twice a semester.

Case study: Understanding force

This case study on contrastive teaching and learning was carried out in a grade 11 advanced physics course over two weeks (10 lessons for phases 1 to 6). It aimed at motivating students to test and further develop their ideas on "force" by means of self-developed problems out of the topic domain "collisions".

Stage 1: Preparation

The unit was preceded by the introducing Newton’s laws of motion. Experiments on an air track were carried out by the teacher to derive $F=m\cdot a$. Several textbook problems with calculations of velocities, distances, and time intervals were posed.

Stage 2: Initiation

As a frame topic the teacher proposed the *investigation of collisions*. The students were prompted to form groups and formulate precise questions in this field together with appropriate experimental settings that could help to find the answers. All materials from the physics cabinet were at their disposal. The students were ensured that the evaluation of their work would not depend on formal conformity with textbook explanations but rather on creativity and internal plausibility of their own results — even if they deviated from the textbook. Their reports were to show the steps taken in the investigations and not just the results.

The students had about 45 minutes time to formulate concrete questions. They were asked to list all ideas that came into their minds. At the end of the initiating lesson of the groups presented their ideas in a class forum. A typical idea was:

> "We want to investigate various effects of impact with cars, e.g., that one car hits the other into its side or head on — or that one of the cars also has a velocity when the other one hits it. (...) We would like to measure the *force of impact*. And we thought we could quantify this somehow — we believe that the force can be calculated. (…) We want to measure the *transfer of force* — how much *energy* is left after the collision."

Two types of investigations prevailed in the students' spontaneous ideas as well as in the subjects finally chosen:

a) to investigate the transfer and preservation of *force*-/"*energy*",
b) to determine the *impact force* of/on a moving body.

Stage 3: Performance

The activities of all the groups centered around the questions mentioned above. The underlying ideas of ‘force’ goes as follows: Moving bodies *have force* which is actualized during the impact and transferable to other bodies. This force can be measured from the resulting effects, i.e., either from the velocity given to the body pushed or from its plastic deformation. The aspect of time intervals, so essential for Newton's definition of force, was considered by none of the groups.

Newton's definition of force had almost no significance for the choice of subjects and the problem solving processes (except for group 5 as shown below). From the preceding instruction about inertia and the interrelation of force and acceleration only the equation $F = m\cdot a$ was taken up. Some of the groups tried to quantify the force of moving bodies by connecting this "formula" to their intuitive energetic understanding of force.

All six groups produced extended reports about their ideas and experiments. The students were requested to document the origin of their questions and intermediate ideas as well as the results. They developed many creative ideas to find answers for their self-defined problems.

Group 5 worked on a problem directly referring to the preceding unit on Newton's laws. The students examined whether the formula F=m·a was really suitable to quantify all aspects of what they understood to be 'force':

> "We wanted to calculate the force that has to be exerted on a vehicle on the air-track so that it gains a certain measurable velocity. We then thought that the force of the sphere rolling down the inclined plane is F=m·a. Calculating the force and measuring the velocity, we could interrelate these two aspects. But this was of course complete nonsense as the F in the formula is the force acting on the sphere and not the one exerted by the sphere. We thus put the question whether the formula could still be valid for the force exerted by the sphere. However, we found contradictions in two different ways:
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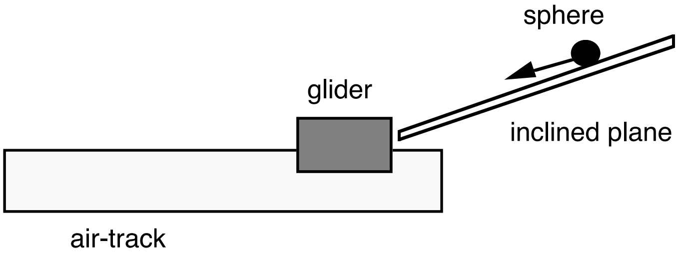
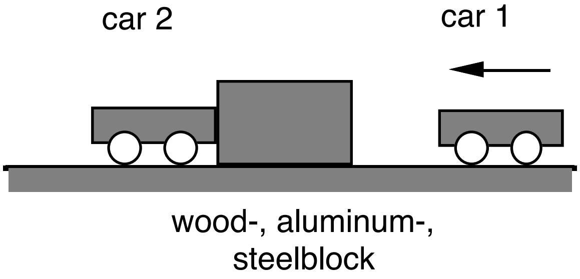
> 
>
>
> Figure 1: Experimental arrangement of Arnim and Ulf
>
> 1. By deliberation: The mass of the sphere is always the same, so the force exerted by the sphere would also have to be always the same. It would therefore be of no significance from which height we let the sphere roll down. The car would always gain the same velocity as the acting force was always equal. This seemed absurd from pure logic.
>
> 2. By experiment: This was confirmed by the experiments. The sphere rolling from different heights resulted in different velocities of the car.
>
> 3. We then wanted to relate the forces and therefore needed the correlation of the accelerations. But the car achieving an acceleration from 0 to 100 in practically no time (first it stands, then it runs at a constant velocity), we could not state any acceleration on the air-track."

The train of thought is described logically. Arnim and Ulf found out in the end that *acting forces* are deduced from accelerations. The force exerted from the sphere on the car could be calculated from the acceleration of the car which, however, is not measurable. The students further found out that the "force exerted (or exertable) by the sphere" and the force "acting on the sphere" are different things and that F=m·a is valid only for the latter case.

Markus and Andreas (group 6) chose the problem: "How does a force act through a heavy obstacle?" A car coming from the right hits against a block behind which a second car stands. The velocity (rather speed) of car 1 before and that of car 2 after the push were thought to give information about the *transfer of force* or *loss of force*, respectively.

> "To investigate where the force was going we wanted to calculate the force of car 2 after the push by the formula F=m·a, with the acceleration being derived from $[(\Delta s/\Delta t)/\Delta t]$. Even before we knew from where to take t we saw our first error: We

> could not calculate the forces of the cars by F=m·a as the cars did not accelerate at all but rather had a uniform velocity.
>
> 
>
>
> Figure 2: Experimental arrangement of Markus and Andreas
>
> We postponed the question whether force could be calculated in some other way or whether it was really force what the cars had, and tried to draw some conclusions from the velocities. (...)
>
> Conclusions: Acceleration results from a force acting continuously. In this sense there is force. In case of uniform motion the force acts only once — as a starter. Afterwards force is no longer present. Instead of that a body moving at constant speed must have energy that becomes noticeable when it hits another object. This energy must be proportional to mass and velocity. We called it kinetic energy".

Concluding their ideas Markus and Andreas differentiate *force* resulting in acceleration of a body and *energy* of the moving body. As in Arnim's and Ulf's work the cluster concept of force started to break up when the students had opportunities to develop their own ideas over a longer time and to test their definition of force on a subject chosen by themselves. The awareness of differences was particularly triggered by the formula F=m·a which proved to be inappropriate to quantify what they understood to be 'force'.

Stage 4: Discussion of findings

Within the general subject of collisions all groups had worked on problems around the definition of *force*. The groups reported their investigations and conclusions in a class forum. The teacher listed some central statements on the board trying to keep to students' words. Here the excerpt from the transcript starts:

Teacher: On the board we very often find the word 'force': force of impact, starting force, force of the car, exerted force, force is transferred. Does the word force always refer to the same thing?

Markus: In our case — what we had with the uniform motion, I would not define this as force because — during acceleration the force is acting continuously. Therefore it is presumably present. In case of a uniform velocity the force acts only once as starter for velocity and can then no longer be in the car. I would therefore describe the rolling car in our case — what is in it — to be kinetic energy.

Arnim: I would, for example say — concerning the force exerted and the force of the car — that the car has some sort of force and can transfer this afterwards. And in other cases it's the force that's exerted. That's the difference.

Claus: I would say that the car running along the track has kinetic energy. I always call that energy. Then the kinetic energy is transferred into deformation energy — if you can say so — relating to the spring (spring fitted to experiment vehicle, the author).

> This spring transfers this energy again to another spring resulting again in kinetic energy — energy thus being transformed again and again.

The students propose a distinction between several types of forces (Arnim) or even to use different terms "force" and “energy" (Markus, Claus). The discussion has reached a state similar to the situation of physics in the second half of the 19th century. This was a chance to introduce an extract from a Helmholtz text published in 1861, that calls for a distinction between the "intensity of force" (today *force*) and the "total amount of driving force" (an aspect of today’s *energy*).

Stage 5: Comparison with scientific theory

In contrastive teaching original texts are presented only *if* and *after* the students have elaborated a similar approach. They are not treated as historical documents (“What did Helmholtz think about ...”), but as illustrations of views that are still virulent in today’s thinking. Historical discussions can thus play an important role in helping students develop conceptual awareness (Schecker, 1992). Students can be encouraged for self-directed work, when they learn that results differing from the textbook may have been held by famous scientists.

> Herrmann Helmholtz: "About the application of the law of conservation of force ("Kraft") on the organic nature" (abridged from Samburski, 1978, pp. 518):
>
> "The most distinguished progress of the natural sciences in our century was the discovery of a universal law which covers and governs all the different branches of the physical and chemical sciences. This law is today called "the principle of conservation of force". A better denomination might be that of Mr. Rankine who speaks of "conservation of energy" because the law does not relate to what we normally call intensity of force. It does not mean that the intensity of natural forces is constant but rather relates to the total amount of driving force won by some natural process, by which a certain amount of work can be done. (...) There is, however, still another type of mechanical driving force, and that is velocity. If the velocity of a body does work we call it vis viva or living force of a body. The enormous force of a canon ball only depends on its velocity."

The teacher had prepared the text as a handout because he expected from research into students ideas about force, that the class would probably arrive at similar ideas. After reading the text and clarifying its content the teacher asked (excerpts from a longer transcript):

Teacher: Can you draw any conclusions from this text for your experiments? Or can't you see any connections?

Lorenz: I mean — Helmholtz uses alternating concepts. He does not decide.

Teacher: What do you mean with "he does not decide"?

Lorenz: At one point he speaks of force that is transformed — as I just said from one sphere to the other —, then he speaks of force that is exerted. I don't really get that. This other guy, this Rankine, he suddenly speaks of energy. He speaks of energy instead of force. That's where the two differ. The concepts are not clearly defined.

Teacher: Helmholtz proposes rather to speak of conservation of energy instead of the principle of conservation of force. Does he keep to his own proposal?

Ulf: No, he doesn't. He still calls it force. For example in his last sentence: "The enormous force of a canon ball only depends on its velocity." I would say, that’s just the energy, which the bullet has, when it is launched.

A physically sound understanding of force and energy can only develop in a process of mutual delimitation. It becomes clear how the students are stimulated by critiquing to differentiate between Newtonian *force* and *energy*.

Stage 6: Reflection

In the case study stage 6 was not done as a separate phase of the unit. Parts of the reflection stage were included in stages 4 and 5. Thorough reflection of the problem solution process becomes particularly noticable in the comprehensive reports that the students produced after the 10-lesson-unit (cf. the quotes from groups 5 and 6 above).

Conclusion

Classroom observations and the students' reports show clearly, that the contrastive teaching/learning unit on collisions propagated qualitative conceptual understanding of *force*. The students were confronted with consequences resulting from their current perspective that they worked out themselves. It was a substantial step towards establishing the scientific view in explicit contrast to intuitive thinking. The preceding teacher-oriented instruction had not succeeded in helping students develop a physical understanding of force. The students had simply added formal elements of Newton's concept as another facet to their undifferentiated everyday-life force/energy/thrust preconcept.

Constructivist and conventional teaching have different aims. Case studies do not provide statistical evidence for positive effects compared to conventional strategies. However, students from the class scored significantly higher in a questionnaire on conceptual understanding in mechanics than the average of about 250 students.

Current research in our institute goes on in the field of quantum mechanics. Starting from the students' picture of the atom as a small solar system, contrastive teaching is employed to help students gain new views of electrons and nuclei (Petri & Niedderer, in press).

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