Promoting students' understanding of Newtonian mechanics through an alternative content structure – Results from an empirical study

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Abstract:

Students' understanding of mechanics – even after instruction – is fragmentary. This is due to the complexity of the topic itself, students' misconceptions and also the quality of instruction. In a Design-Based research oriented empirical study was investigated, which influence the use of different content structures for teaching had on students' understanding.

For this study, the effects of two content structures were assessed in a quasi-experimental field study with ten teachers, their grade seven classes (n = 27) and more than 500 students. Instruments used in a Pre-Post-Follow-Up-Design were a self constructed knowledge test as well as surveys on interest and self concept. Furthermore, interviews with all participating teachers and selected students were conducted.

As result we found significant differences with middle effect sizes in the two groups. One of the content structures promotes students' understanding; no significant difference was found in students' interest and their self concept. Students' interviews showed a deep understanding of the concepts of Newtonian mechanics in one of the populations.

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1. Introduction

Students' understanding of mechanics – even after instruction – is fragmentary (e.g. Hake, 1998). That teaching for conceptual change for students' is so difficult is due to the complexity of the topic itself, students' misconceptions and also the quality of instruction (e.g. Treagust & Duit, 2008). Good evidence exists that increasing students' activities fosters their understanding (Hake, 1998), but apart from this result, only little is known, what one can do to promote students' understanding of Newtonian mechanics, which is a big problem for physics teachers. Especially in Bavaria (Germany) this was a major issue among the physics teachers since the last curriculum reform put Newtonian mechanics into grade seven. To teach this content to 13-year-olds did not work very well for the majority of Bavarian physics teachers.

So in a Design-Based Research approach (Design-Based Research Collective, 2003), we tried to identify possible approaches for a solution and simultaneously to investigate the effects of a conceptual development strategy (Treagust & Duit, 2008). We decided to investigate the effects of content structure: There are different ways to teach mechanics, which are discussed in the literature since decades (e.g. Jung, Reul & Schwedes, 1975), but only few empirical studies exist, which compare different ways to teach physical content (Smith & Wittmann, 2007; Starauschek, in print).

In the study presented, two different approaches towards teaching Newtonian mechanics in grade 7 were compared: The first course was based on an instructional design starting with the introduction of speed and acceleration in one dimension and continued with the discussion of forces and Newton's laws. This course is the usual teaching sequence for seventh grade physics in Bavaria. Therefore educational materials exist. The alternative course on the contrary started right away discussing two-dimensional motions and consequently focused on velocity as a two-dimensional (vector) quantity. Newton's second law was introduced using the impulse equation. For this course, teaching materials had to be developed. This development was based on the theory of p-prims (DiSessa, 2008); the relevant p-prims were identified in many previous studies (for an overview see Author, 2010).

For the empirical study, the following hypotheses were chosen:

(1) Students taught with the alternative course outperform those taught the traditional course.

(2) The alternative course results in a deep conceptual understanding of the students.

(3) The alternative course promotes students' interest and self concept

2. Methods

To find answers, a comparative empirical study in 7th-grade classrooms was planned and carried out. 10 teachers participated with their classes: In summer 2008, they taught their 7th-grade classes in the traditional way (Control Group, CG; 14 classes, N = 266); in summer 2009 they taught new 7th-grade classes with the alternative curriculum (Experimental Group, EG; 13 classes, N = 255). In this way, the same teachers taught both curricula, but were unbiased by the new ideas during their teaching in the control group. For both groups the teaching time was 20 lessons and teachers kept a diary about their teaching.

In autumn 2008, the developed materials were pretested with 17 classes and revised due to the results. In spring 2009 the teachers of the main study were informed about the new curriculum and obtained the teaching materials as well as student textbooks for the alternative course during a half-day CPD-seminar.

Since the age of the assessed students, it seemed not appropriate to use standard knowledge tests developed for college students as FCI or FMCE. Instead a new knowledge test was used, which contained some known items (e.g from FCI). In this survey, items fair for both curricula was used as well as some items, which fitted for either one or the other curriculum only. Students' interest was assessed with a PISA-based questionnaire, self concept with a questionnaire by Helmke (1992). All tests and questionnaires were given as pre-, post- and follow-up-tests. In a replication study, the same approach was repeated with a smaller sample of teachers (n = 5) and students (n = 140 in CG and n = 97 in EG).

To test the understanding of students, 52 semi-structured interviews with a random sample of EG students were conducted.

3. Results

The analysis of the data shows, that hypothesis (1) can be accepted: Students from EG outperform those from CG highly significant with a large effect size (d = 0.89). This effect only drops slightly from post- to follow-up-test. It is even more interesting to do some detailed analyses of the knowledge test data. Therefore three subscores of the knowledge tests were computed and analysed separately. As expected, students from EG did best on items, which fitted for their course (d = 1.30). But on the contrary, students from EG and from CG performed almost equally on items, which fitted for the CG-course (d = -0.1). Again, students from EG outperformed the others on items fair for both curricula (d = 0.56). A further result is promising: In more detailed analyses of the data, a significant interaction effect between gender and group could be found. Whereas in CG boys outperform girls over the period of the

study, in EG the significant difference in pre-test disappears in post- and follow-up-test. Another interesting result was, that the teaching time only in EG did influence the learning outcomes. In CG the outcomes were independent of the time the teachers had taught the course.

To test for hypotheses (2), the interviews of the EG students were analysed. More than 90 % of the 7th-grade participants were able to use vectors to describe velocities and the addition of velocities. More than 50 % of the participants had a deep understanding of Newton's second law and could solve a real world problem using it. So also hypothesis (2) can be accepted.

Hypothesis (3) had to be rejected: No significant differences in students' interest or their self concept could be found between the two groups.

All of these results could be replicated in a smaller sample.

4. Conclusions and Implications

As our results show, the alteration of the content structure has a large influence on students' learning. The orientation on students' ideas to build a curriculum (diSessa, 2008, Author, 2010) paid off: Students understanding was much better and deeper than in the traditional approach. Furthermore it reduced the gap between the performances of boys and girls. Changing content structures of physics education seems a promising approach regarding to our results.

There is another benefit of our work: The developed teaching materials and texts are available for every teacher who wants to change his teaching. Most of the teachers from our population reported, that they will continue to use the alternative course for their seventh grade classes. For other teachers we have made available the material on our websites. So the Design-based research approach identified a possible solution to the initially formulated problem.

We also are confident, that teachers can profit from the use of the materials: Usually it is reported, that only longer CPD-courses can influence teachers' teaching. In our study, a half-day course for the teachers and supplying them with appropriate materials lead to significant differences in students' performance. This should be investigated in more detail in future studies.

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