POINT DE VUE

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Recherche et dévelopment en didactique de la physique à l'université; résultats et tendences.

Research and development in Physics Didactics at University; issues and trends

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Research and Development in Physics Didactics at University - Issues and Trends

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Abstract
University physics education world-wide is in a process of development and change. Important deficiencies of university teaching are often a low level of motivation followed by decreasing enrolement numbers, and a lack of qualitative understanding of basic concepts in physics. Physics didactics can contribute to improvement with development of new teaching approaches and research about motivation of students and their understanding of basic concepts. The following article discusses relevant directions of research, related research questions and exemplary results. Lectures and labwork deserve careful thoughts to become more motivating for students and more effective for learning. Important principles are more interactive forms of teaching in lectures and more efforts to connect theory and practice during labwork, not only with "hands-on", but also with "minds-on".

1 Introduction

University physics education world-wide is in a process of development and change, best documented in a recent book "the changing role of physics departments in modern universities" (Redish et al. 1997). One reason for this new dynamics comes from students themselves: many do not find physics a valuable subject to study anymore and so enrolment numbers go down, and departments feel the need to do something. Another reason comes from results of didactical research: the outcome of "traditional" introductory physics courses with respect to students' conceptual understanding of physics seems not sufficient (Nachtigall 1985, McDermott 1997, Hake 1998a, Mazur 1997). From Hake's paper, we can also see the main trend which is coming out of this discussion to improve the situation: courses have to become more interactive, in many different respects, in interactive parts of lectures as well as in interactive labs, adding "heads-on" to "hands-on" (Hake 1998b). The same tendency is pinpointed by Lunetta (1998) with respect to labs: "To many students, a 'lab' means manipulating equipment but not manipulating ideas". The focus of the following paper will be on empirical studies related to students' understanding and learning of physics[1]. This type of research has developed a substantial body of agreed results on students' alternative frameworks related to all content areas in physics during the past 20 and more years (Pfund&Duit 1998, Driver et al. 1995). A more recent research focus are learning process studies in physics (Duit, Goldberg, Niedderer 1992). All this research has led to change the focus of

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[1] Other types of research in physics didactics are more related to the physics content itself, related to new experiments, the use of new technology, better understanding of modern physics etc.

teaching from a more transmissive view to a more constructivist view of teaching (fig. 1).

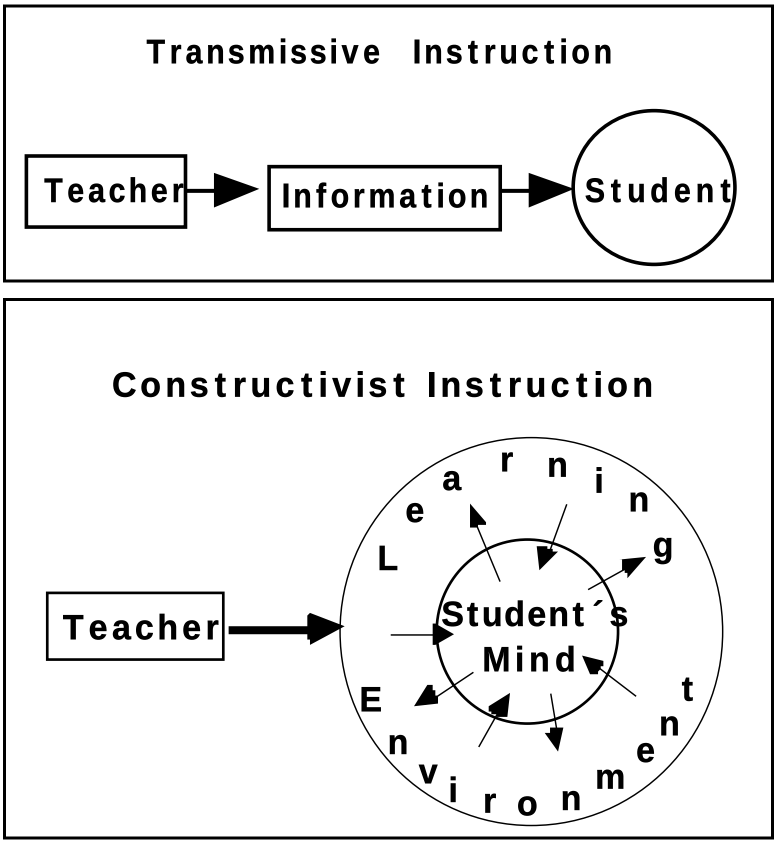

Figure 1: **Two different views about teaching and learning**

The main difference is to be seen in that the transmissive view assumes that teaching information can be learned directly by the students in a process like copying the given information, e.g. from a professor's presentation in the lecture, whereas in a constructivist view of instruction the teacher with talks and other information in lectures, with labs and group work can only establish a learning environment. But the main processes going on in students' minds are determined by students' own thinking, ending in a constructivist process of thinking and learning, building up a special understanding which might be quite different from what the intention of the teacher was. Empirical studies with university students (Nachtigall 1985, Galili et al. 1993, Thornton 1997, Hake 1998a) have shown that many students after introductory physics courses very often hold conceptions which can be quite different from what they were expected to learn. A more constructivist view of teaching and learning would be in favour of more interactive type of lectures (Mazur 1997, van Heuvelen 1997, McDermott 1997, Hake 1998b) and more active and interactive types of labwork in physics courses at university (Bécu-Robinault&Tiberghien 1998, Niedderer et al. 1998). It would provide more chances for students to become active during learning, to "experiment with ideas" (Lunetta 1998), and would provide more feedback both to students and to teachers.

2 The role of research in didactics (physics education) in university teaching

In general, the role of research in physics didactics in universities depends on the readiness of professors and other teaching staff to accept teaching both as a relevant and problematic part of their work which can be improved by co-operation. Our experience is, physics faculties both in Germany and in the US were more reluctant in the past, but are becoming more aware of teaching issues as they face some problems with decreasing enrolment of students. If this is the case, co-operation between teaching staff and people from physics education research becomes important to start some innovation processes. These negotiations themselves could also be the focus of an important type of research, investigating the understanding of university teachers about teaching, and its development over time (Fischler 1994). From my point of view, four aspects of innovation seem most important:

- more interactive parts in lectures, including short phases of group work with feedback from other students as well as from the teacher;
- innovation in contents and type of activities in labwork (clarifying objectives and restructuring labs and labguides according to these objectives);
- including new technology into teaching and learning of physics;
- including labwork with hands-on and "minds-on" and mini-projects can significantly contribute to the objectives "to link theory to practice" and "to improve the quality of scientific thinking in general"

With respect to innovations of these types, the roles of research in physics didactics for university teaching can be the following:

- didactical research in university teaching gives more attention to teaching and learning, and thus can be a motor for innovations.
- didactical research has developed methods to analyse many aspects of teaching, about motivation and interests of students as well as about their understanding and learning of physics; they can be used to control the effectiveness of traditional and innovative approaches.
- didactical research today comes from a constructivist theoretical base of teaching and learning, resulting in teaching strategies, which can help to come to more interactive forms of teaching;
- didactical research has developed a body of "pedagogical content knowledge (PCK)" which includes knowledge about typical conceptions of students, about new media and new technology, new didactical approaches, and other aspects. This can be useful in informing teachers at universities.

3 Types of research in didactics which can be useful to University

3.1 Research related to physics motivation and interests of students

A crucial problem in physics departments at universities is the decreasing number of students who decide to take physics, and the increasing number of students who after some time (typically one year) become disappointed by difficult and not motivating introductory physics courses and leave physics. So problems with motivation of students to choose physics as a subject of university studies is one of the big issues in the present crisis of physics departments. Therefore didactical research in this area is very important, and should pay attention to the investigation of motivation and interest of students.

Typical research questions could be:

- What kind of topics, type of teaching and media are interesting and motivating for students?
- What are students' expectations when they start physics at university?
- During a special introductory physics course: What is interesting, what is boring for students?
- What are students' reasons to leave physics after some time of studies?

Methods of research have been developed in these areas, they have been more used in relation to high school science than to university physics so far (Fischer&Horstendahl 1997). Methods like interviews, open-ended questions and special interest questionnaires where students are asked to rate their interests with a lot of pre-formulated items have been developed and used (Häußler 1987).

We give some selected results related to university physics education. Von Aufschnaiter et al. in a study with 25 second year university physics students have found, that in a general sense they were rather pleased with studying physics, but they comparatively were much less pleased with what they were asked to do in the physics lab (von Aufschnaiter et al. 1997). Another more specific result is related to the use of computers in physics education at universities: Teachers see experiments using modern technologies as a motivating factor, to develop interest and to enjoy subject and activity, more than it helps to link theory and practice or to develop experimental skills (Welzel et al. 1998). Another specific result about motivation comes from an unpublished own open-ended questionnaire with 30 first year university physics students in Bremen: for them the newly introduced "miniprojects" (3 weeks at the end of a semester working in the lab with own research questions) were one of the most motivating aspects of the whole course.

3.2 Research related to physics understanding of students

Research on students' understanding of physics at all age levels has been a major effort in physics didactics during the past three decades. This research has achieved a huge body of knowledge about students' alternative conceptions related to key concepts of physics. Many parallel studies in all continents have come to partly overlapping results, which are documented in journals and books (Pfundt & Duit 1998, Driver et al. 1995). Even results at the university level indicate that the difference between what is taught and what is learned is much greater than most instructors realise. There seems to be a serious mismatch between how physics is traditionally taught and how most students learn, especially at the introductory level (Mazur 1997, McDermott, 1997). Some of the new interactive approaches to university physics teaching in the US are: "Workshop Physics" (Laws), "Peer Instructions: Getting students to think in class" (Mazur), "Physics by Inquiry" (McDermott), "Using Interactive Lecture Demonstrations to Create an Active Learning Environment" (Sokoloff & Thornton), "Using Interactive Simulations to Enhance Conceptual Development" (Van Heuvelen) and "Learning Cycle Physics" (Zollman), all with contributions in Redish et al. (1997).

So, out of this issue in university physics education, several research questions arise for physics didactics:

- How can understanding of basic physics concepts be improved? This question is related to all aspects of the learning environment of introductory physics, such as content, lecture, labwork, group work of students, etc.
- How can the understanding of students be evaluated? It seems clear that tests like the FCI have a limited validity, other methods (see below) should be used complementary.
- What kind of knowledge do students have after introductory physics courses? (Ability to solve problems, ability to use mathematical tools, understanding of basic concepts and laws)
- What are possible layers or components in students' knowledge after teaching? (Petri&Niedderer 1998)
- How much knowledge is gained by different courses, with different approaches (pre-post differences)?

In the United States some instruments have been developed to provide broad assessments of student understanding, especially in mechanics. These are: The force concept inventory (FCI) by Hestenes and Halloun, the mechanics base line test (MBT) by Hestenes and Wells, the force and motion conceptual evaluation (FMCE) by Thornton and Sokoloff and a test of understanding of graphs in kinematics (TUG-K) by Beichner (see McDermott 1997, 142). Similar tests in other content domains are currently developed (see home page of P. Laws). But other methods should be used to get complementary qualitative results about student understanding. Some of these methods are: Written open ended questionnaires with "thinking-type questions" (Schecker 1988), interviews with individual demonstrations (McDermott 1997), or experimental hands on interviews (Schecker et al. 1998).

In this paragraph, some selected results about understanding after introductory physics courses in universities are reported. In Germany, Nachtigall (1985) carried out investigations about physics students after having finished introductory physics courses. One of his results was that more than 50 % of them hold non-Newtonian force conceptions at the end of those courses. In America Hestenes and others developed a special test to detect the understanding of a Newtonian force concept, the so-called "Force Concept Inventory (FCI)" (Hestenes et al. 1992). This test was used by Hake in a huge study with about 6000 students to analyse understanding of the force concept in different kinds of college and university introductory physics courses in America. He found little gains in understanding in so-called "traditional courses", whereas he found higher gains in so-called "interactive courses". But he found nearly no courses with more than 70% of the possible gains (Hake 1998 a).

In our group, we have done a small investigation of this kind to check the effects of several innovations in an introductory physics course for prospective teachers at universities (Sander & Niedderer 1998). We changed the lectures to more interactive forms of lecturing, we incorporated new technology - especially a modelling software (STELLA) - into lecture and labwork, and we changed the labguides to more open ended tasks. We analysed the effects of all this in a control group design, comparing pre and post tests with the FCI and MBT tests in this innovative course and in a parallel, more traditional course for physics majors. The level of the physics major students was higher both in pre and post tests, but not sufficient. Yet, the gains in the innovative course (average 16%) were higher than in the traditional course (average 11%), but not as good as we had expected or hoped. So, this kind of results shows the need for more detailed investigations, related to the analysis of effects of specific parts of the learning environment.

3.3 Learning processes studies and teaching experiments.

There are two major issues related to these investigations about understanding. One is that they give overall results of understanding at the end of a course, but they don't give information about the learning effects of single specific parts of the learning environment, such as specific contents, lectures, labs, tutorials, etc. This issue leads to "teaching experiments" (Duit&Komorek 1997, Niedderer&Goldberg 1995). The other problem is that those studies tend to analyse only whether or not a scientific view is achieved by students at the end of a course. They do not take into account the possibility of new intermediate conceptions constructed by students, by analysing the final state in more differentiated way or by analysing the cognitive process going on during the whole process of learning during the whole course. This issue can be overcome by carrying out "learning process studies" (Niedderer et al. 1992, Tiberghien 1997). Both types can be combined to give optimal results. So far, they mostly have been done with small amount of students, so they can give insights of a qualitative kind, but only in few cases analyse statistically learning processes of large numbers of students (Thornton 1997). Generally speaking, this type of research has shown that normally we find intermediate conceptions or intermediate notions between everyday life conceptions and what is the intended scientific concept of the teacher. Dykstra (1992) describes a series of conceptual changes related to the concept of force. He names the different conceptions as (1) initial conception, (2) refined initial conception, (3) first version Newtonian conception, and (4) refined Newtonian conception. Tiberghien (1997) speaks of intermediate notions of heat and temperature. She, from her empirical investigations, describes those intermediate notions which have been developed by students and lie between their initial everyday life conceptions and what was intended by teaching. From these investigations, she re-formulated more realistic objectives for teaching: " The aim is to allow the design of teaching situations more relevant for learning". Galili et al. (1993) speak of intermediate states of learning in geometrical optics, Thornton (1997) speaks of conceptual dynamics, following the changing student views of force and motion. In teaching experiments, a special teaching approach is taught to a small number of students in a kind of laboratory set, the whole process is video- or audio-taped, afterwards transcribed, and special care is given to the resonance of students to specific parts of the learning environment. All this is analysed with qualitative interpretive methods. Niedderer and Goldberg (1995) have described such a teaching experiment with 3 college students in the field of learning electric circuits.Sander and Niedderer are analysing effects of using a computer software for modelling (STELLA) integrated into labwork in university introductory physics courses in a similar design (Sander&Niedderer 1998). Komorek and Duit have done this kind of teaching experiment in the field of deterministic chaos (Duit & Komorek 1997). Smolé, Schoster and von Aufschnaiter are doing similar investigations with students in grade 11 and in labs in university physics, using special cards as well defined teaching information for students and analysing their effects with respect to the level of complexity of teaching information as well as of students constructions (Schoster & von Aufschnaiter 1998).

Possible research questions in this type of research are:

- What are the intermediate states of knowledge in the learning process during one course?
- What is the state of knowledge at the end of a specific course?
  We assume, that not only one view, one conception - either scientific correct or more from everyday life - is to be expected, but rather that students after teaching have different views, different conceptions, available. We speak of different layers with different strength and status (Petri&Niedderer 1998).
- What is the effect of specific parts of the learning environment on the development of students' knowledge?

There are several possible designs of those studies, focusing more on pre-post designs or on a kind of stroboscopical picture of several snapshots over time or on process studies which take data from the whole process, but from only few students (Niedderer et al. 1992).

3.4 Research related to lectures

Lectures in university physics often are rather traditional. They see their main purpose to give competent and relevant information as clear as possible to students. They more or less assume that this information is taken by students, and this means learning (see Fig. 1). A more constructivist view of learning would certainly try to add more active and interactive engagement on the side of students. There are several suggestions of this kind, from peer instruction (Mazur 1997) to other forms of interactive lectures (van Heuvelen 1997) and the extreme version to have no lectures at all (Laws 1997). The famous learning cycle (Zollman 1997) is also an example of this kind to introduce more interactive forms into lectures.

Because the role of lectures to some extent is crucial for university teaching, research should focus on the effectiveness of lectures. This can be done in principle only with methods closely related in time to one lecture. Students can be asked with open ended questions after each specific lecture what they have learned, or more general, what they have gained from this lecture. In addition, interviews to test their understanding of the content of the lecture could be done.
Possible research questions could be:

- What is the contribution of lectures to understanding and learning of physics?
- What is students' view of different types of lectures?
- How do the effects on motivation of students and learning of physics differ between different types of lectures?
- What are the main criteria for good teaching in lectures from the viewpoint of students?
- What is students' view of learning, more passive or more active, what is their metacognition about learning (Gunstone 1992).

3.5 Research related towards use of new technology

Computers can be introduced to the teaching of physics at university in many ways: They can be used in lectures and labs, for data collection and real time graphical display of results as well as for theoretical modelling, in computer labs in university and at home at the own PC, perhaps connected with internet (Goldberg 1997, Niedderer & Schecker 1997, Thornton & Sokoloff 1990). There are interesting results about positive motivational effects of using new technology, and also positive results about using interactive microcomputer-based lecture demonstrations (Thornton 1997) as well as positive results about using model building software like STELLA (Schecker 1998, Niedderer et al. 1998). On the other hand, from experiences of practical use of computers in lectures and in labwork, there are a number of serious issues. One hypothesis, for instance, is that the use of computer instead of promoting learning and communication can lead to a more technological use of software with clicking around here and there and therefore even avoid thinking.

So research in this field seems important and relevant. Some possible research questions are:

- What are positive and negative effects of using new technology on motivation of students?
- What are positive and negative effects of using new technology on understanding and learning of physics?
- How can computer technology be used to promote motivation and learning and of physics students?
  This research question has to be analysed for different types of software, for lectures and labwork separately, resulting in better teaching strategies for lectures and better guidance of labwork by tutors and labguides.

3.6 Research oriented towards labwork

Labwork in physics education at universities can serve different objectives (Welzel et al. 1998). Perhaps the most important objectives are to link theory and practice, to develop experimental skills and to promote motivation of students for studying physics. There are a number of research results which seem to indicate that traditional labwork in university at least fails to promote the first and third of these objectives, it tends to guide students to work with labguides like recipes, more with "hands-on" than with "minds-on" (Lunetta 1998). On the other hand there is research and development going on, which shows that certain changes in labguides and the training of tutors and more open ended labwork can have positive effects (Bécu-Robinault&Tiberghien 1998, Niedderer et al. 1998).

Some selected specific hypotheses out of the European project "Labwork in Science Education" (Séré et al. 1998) related to labwork in universities are:

- Different forms of labwork (more or less open ended, hands-on and demonstration experiments) are necessary for different objectives. In a sequence of labs different forms should be combined in order to facilitate learning of different types of conceptual and procedural knowledge by students
- Teachers and/or teaching staff (at university) play a crucial role in labwork. Special guides for teachers and teaching staff and training programmes have to be developed. These guides should support effectively the learners to reach the above named objectives.
- A third hypothesis is related to the structure of labguides with respect to the amount of guidance. From the analysis of a survey (Tiberghien et al. 1998) we know that most labguides are strongly guided. On the other hand from the survey on objectives for labwork (Welzel et al. 1998) we know that teachers - and especially students - see a high potential for better link of theory to practice and for development of scientific thinking with open ended labs, so perhaps there should be a development of experimental skills with more guided labs and an improvement with

linking theory to practice and development of scientific thinking with more open ended labs. To use a special strategy of explicit activities of students to "predict-observe-explain (POE)" (Champagne et al. 1985) can also contribute significantly to the objective "to link theory to practice", both with demonstration experiments and with hands-on experiments.

So research questions related to labwork could be the following:

- What kind of learning processes are going on during labwork?
- If specific labwork is aiming at certain objectives: How effective is this labwork in relation to these objectives?
- After a certain training programme for tutors: How have the interactions of the tutor with students during labwork changed?
- If a labguide has been changed: How does this change affect students' work during lab?
- What kind of labwork is motivating for students?

Research in physics education already has started to analyse student learning during labwork by taking video data of the work of single student groups. Continuous videographing of labwork sessions for analysis of students' activities and the analysis of video data for identifying and using certain categories have been used to reconstruct the activities during labwork. Different methods have been developed to analyse these data. One way is to use a qualitative interpretive analysis of video data and their transcripts in great detail to describe learning processes during labwork (Bécu-Robinault& Tiberghien 1998, von Aufschnaiter & Welzel 1998, Sander&Niedderer 1998). On the other hand, the same video data can be analysed without transcripts in a category-based procedure, which can help to evaluate a greater amount of data and classify students' activities during labwork and their effectiveness of using physics during these activities (Niedderer et al. 1998).

4 Conclusion

University physics education seems to be a relevant field for didactical research. The role of didactical research can be to initiate new and better forms of teaching in lectures and labs and control their effects related to motivation as well as to understanding and learning of physics. Several methods have been used, such as tests and questionnaires, different kinds of interviews with and without experiments and methods using video data both from lectures and labs. Some interesting research questions have been listed for the different chapters above. The role of didactical research in the best case can be a motor and quality control for innovations, if colleagues in physics departments realise the need for changes and accept corporation with physics education people.

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