Chapter 5

Solid-State Dynamics and Education

(http://www.eduphys.ethz.ch/)

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5.1 E-Learning and teaching support

30 lectures have been supplemented by the learning management system Moodle in 2014, reaching more than 5’000 students. Moodle was mainly used to support the course organization and to serve as a repository for course material. For some lectures, however, supplementary pedagogical scenarios, such as self-assessment tests, formative evaluations and collaborative tasks have been set up.

The project “video-solutions” started in 2013 could be extended to 6 lectures (MSc and BSc). The Department of Physics provided room and equipment for a recording studio (HPH F 18) where 97 new videos (length 15-25 min each) were produced in 2014. Each of these video clips covers a detailed solution to a physical problem. The videos are highly appreciated by the involved lecturers (Degiorgi, Kirch, Dissertori, Vaterlaus, Pescia) as well as by the students. In 2014 more than 15’000 views were attested (according to youtube).

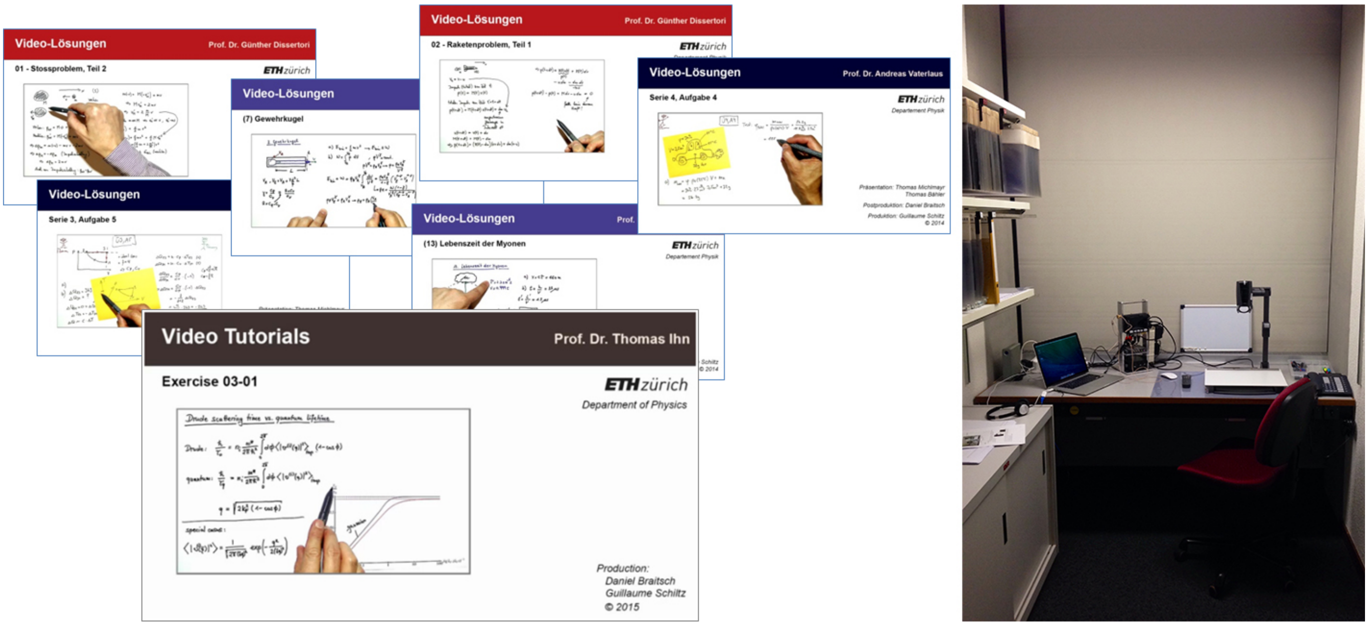

Figure 5.1: Video solutions (available from youtube, channel EduPhys) and the D-PHYS recording studio.

In responding to the repeal of “Testate” two compulsory midterm-tests (Günther Dissertori, Christian Degen) have been implemented. The Exercise-Market was adopted in further lectures where teaching assistants as well as lecturers were trained during a half-day workshop.

5.1.1 Promotion and Network

The teaching activities pursued at the department have been communicated to a greater public at two international conferences.

5.2 Ultrafast magnetism

For ultrafast demagnetization of a ferromagnet, spin angular momentum needs to be transported away from the spin system. Unlike other ultrafast processes in solids, the time scale of magneto-dynamics is believed to be dictated by the transfer of angular momentum. Therefore, the femtosecond magnetization dynamics is of fundamental interest. Laser-induced demagnetization is also of technological interest for magnetic recording devices: in order to optimize hard disks for fast writing times, long data retention times, and high storage densities, conventional writing needs to be combined with pulsed laser heating. The heat assisted magnetic recording (HAMR) technique therefore combines a magnetic field source with a pulsed laser diode to heat up the magnetic bit during writing.

5.2.1 Pump pulse length dependence of ultrafast demagnetization

The demagnetization process is expected to be caused by both, the excited electron gas as well as the lattice. If the ferromagnet is heated by a femtosecond laser pulse, the electron gas initially reaches a temperature, which exceeds the lattice temperature. This initial temperature rise in the electron gas is followed by thermalization with the lattice to a common temperature. In case of excitation by a picosecond laser pulse, the electron gas and the lattice stay close to thermal equilibrium during the whole demagnetization process.

We investigate if the demagnetization caused by a picosecond laser pulse can be described by the same mechanism as the demagnetization by a femtosecond pulse. This is achieved by studying the ultrafast demagnetization dynamics of a Ni film as a function of the pump pulse length. Our experiment demonstrates that the demagnetization by a picosecond laser pulse is described by the response to a femtosecond pulse convoluted with the pulse shape of the picosecond pulse, see Fig. 5.2. Therefore, the dynamics driven by the femtosecond pulse contains all information about the response to a picosecond pulse and is driven by the same physical processes. The demagnetization shows two components. One of them is independent of the pump pulse length and recovers on a time scale of heat diffusion. The second component is only present for pump pulses of less than 2 ps length. We interpret the decay of the fast component to be caused by the fast cooling of the electron gas. The fast demagnetization contribution can be achieved efficiently and quickly, yet, it is not a long lasting effect.

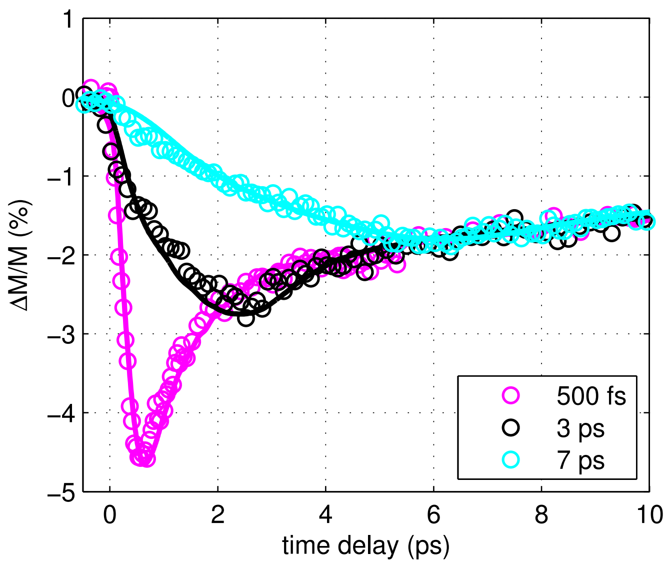

Figure 5.2: Measured demagnetization (circles) compared with the calculated demagnetization by convolution of the excitation pulse with the femtosecond magnetization response (lines).

5.2.2 Development of an imaging spin detector

We developed and tested a novel spin detector based on low energy scattering of spin polarized electrons on a Iridium crystal. The detector has been developed together with the group of Prof. Schönhense (University of Mainz, Germany). Electrons from the output of a hemispherical energy analyzer are elastically scattered on a an Iridium surface (Fig. 5.3). Due to the spin-orbit coupling within Ir, the reflectivity is spin dependent and therefore acts as a spin filter. As the scattering process is elastic, the imaging properties of the hemispherical analyzer can be preserved, allowing for parallel detection of electron energy and emission angle. Therefore, the efficiency of this detector is significantly better compared to a traditional Mott spin detector. This detector has been designed by our group, and has been manufactured by the physics machine shop. First tests have been performed.

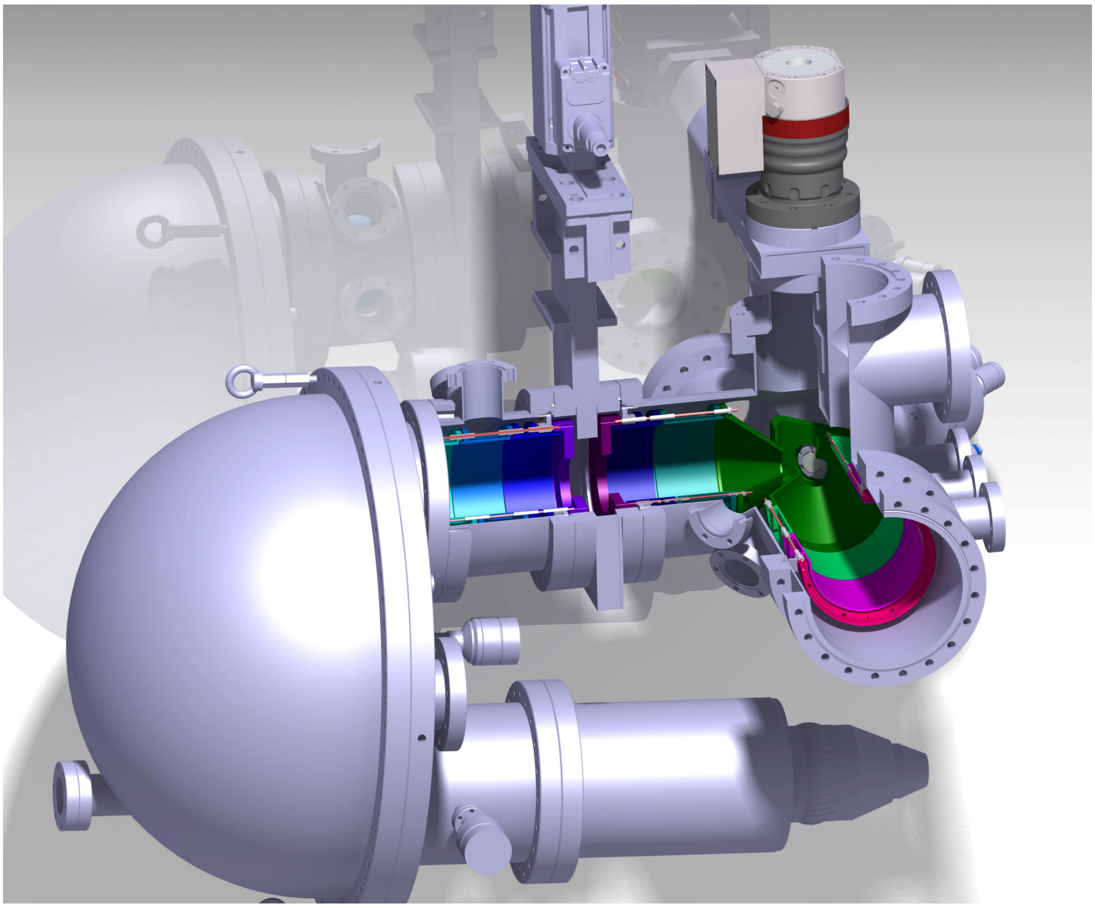

Figure 5.3: Drawing of the SPLEED spin analyzer attached to a hemispherical energy analyzer. The detector has been designed by our group and manufactured at the physics workshop at ETH.

5.2.3 Transport model of ultrafast demagnetization

We developed a model describing ultrafast demagnetization as a transport effect: The pump laser pulse causes a temperature gradient within the first surface layers of the sample. This gradient can be as large as 100 GK/m. The chemical potentials for minority- and majority electrons are altered by the temperature, leading to a gradient of the chemical potentials $\mu_\uparrow$, $\mu_\downarrow$ for the majority($\uparrow$)- and minority($\downarrow$) spin direction. It turns out, that $\mu_\uparrow$ is affected most, leading to a chemical potential gradient, which favors a spin current from the hot surface towards the substrate. Finite element calculations show, that the spin current pulse caused by this effect can be as short as 100 fs. The model is similar in spirit to the super-diffusion model from Battiato et al. (Phys. Rev. Lett. **105**, 027203 (2010)), yet it is based on a thermodynamic concept. It therefore contains the basic process in an analytically solvable form. The results will be compared to experimental data obtained through optical transport experiments.

5.3 Physics Education

5.3.1 SNF-Project: Fostering conceptual understanding of physics by formative assessment

Formative assessment is an assessment procedure without marks or grades. Rather the student can evaluate his or her understanding. For our project we have recruited 31 teachers from Swiss high schools form different parts of Switzerland ranging from St. Margarethen in the eastern part to Thun closed to the french speaking region of Switzerland. Since some of the teachers participate with several classes there are around 800 students involved. The teachers were divided in three groups, a control group, a frequent testing group and a formative assessment group. The frequent testing group solves the same tests as the formative assessment group but without the formative assessment approach. In this way we can distinguish between the effect of frequent testing and of formative assessment. We have developed a concept test of kinematics, which we use as pre-, post- and follow up test. Furthermore we designed two clicker sessions with 15 multiple-choice problems each for the formative assessment approach. The diagnostic test then focuses on the detection of misconceptions. It is followed by a reflective lesson, where the students have the possibility to work on their deficits. We also provided teaching material for the reflective lesson. After a professional development course before summer holidays the different groups started to teach kinematics in the fall semester for 15 lessons including all physics tests (Fig. 5.4). In addition we administrated a cognitive performance test as well as motivation test to the students. However, we did not just evaluate the students but also the teachers. They were tested for their pedagogical content knowledge (PCK). Our major goal is to finish the data acquisition phase of the project in spring 2015 including the follow up test.

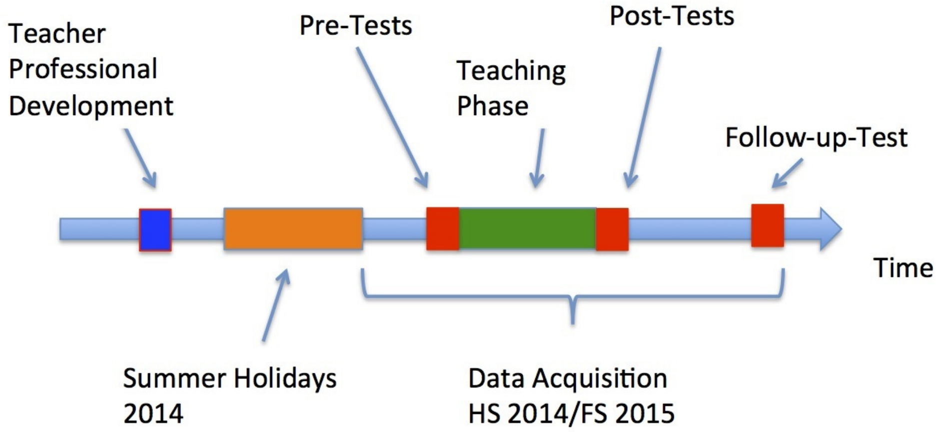

Figure 5.4: Time course of the data acquisition phase of the SNF-project. The PCK test was applied to the teachers during the professional development day. The motivation questionnaire was also administered as pre- and post test.

5.3.2 Correlation between mathematics and physics concepts in kinematics

We have developed a diagnostic test in kinematics to investigate the student concept knowledge at the high school level. The multiple-choice test items are based on seven basic kinematics concepts we have identified. We have performed an exploratory factor analysis on a data set collected from 56 students at two Swiss high schools. We have found that there are two basic mathematical concepts that are crucial for the understanding of kinematics: the concept of rate and the concept of vector (including direction and addition). The context and the content of the items seem to play only a minor role. If a student understands the concept of rate he is able to answer correctly to questions about velocity and acceleration in different contexts. We have further investigated the correlation between the mathematics and physics concepts by adding mathematics items to the test. A factor analysis has shown that the items that are associated to the mathematical concept of rate actually group with the items assigned to the kinematics concepts “velocity as rate” and “acceleration as rate”. Moreover the correlation of the total scores of the mathematics items about rate and the kinematics items about rate has a considerably high value of 0.63. This result has direct implications for the instruction. It suggests that in kinematics courses the focus should be first on the learning of the mathematical concepts. Transferring the mathematical concepts to physical contents and applying them in different contexts is suggested to be easier for students than learning physical concepts without a mathematical fundament.

5.3.3 Understanding Physics Concepts at Different Representation Levels — a Mutual Information Approach

We have analyzed student’s knowledge about physics concepts in kinematics at different representation levels. The concepts, we were looking at, were first, velocity as rate and second, velocity as one-dimensional vector. The problems administrated to the students were multiple-choice questions using different representations. Questions at the first level are associated with figures like stroboscopic pictures. At the second level questions are furnished with diagrams and at the third representation level motions of object were represented by tables. Some of the questions about velocity as rate could be posed at all three representation levels. Correlation analysis is a linear method and doesn't take nonlinearities into account. Correlations can be zero although there is an obvious nonlinear relationship between data points. Thus we have used mutual information to analyze the data (Fig. 5.5), on the one hand to corroborate the linear correlations and to detect nonlinear relations. Our results reveal the same classification as the linear correlation analysis. Students solve the problems due to mathematical concepts like rate and 1d vector. Moreover we have found that the grouping due to representations is given by the solution strategy. Thus, stroboscopic representations of problems and representations as tables use the solution strategy "ratio of differences". It means that the student first has to find the Δx (or Δv) and divide it by Δt to solve the problem. In the case of diagrams the student has to determine first the tangent at one or several time points in order to answer the question. Including the concept velocity as 2d vector, we therefore expect at least five factors in a factor analysis of a large data set.

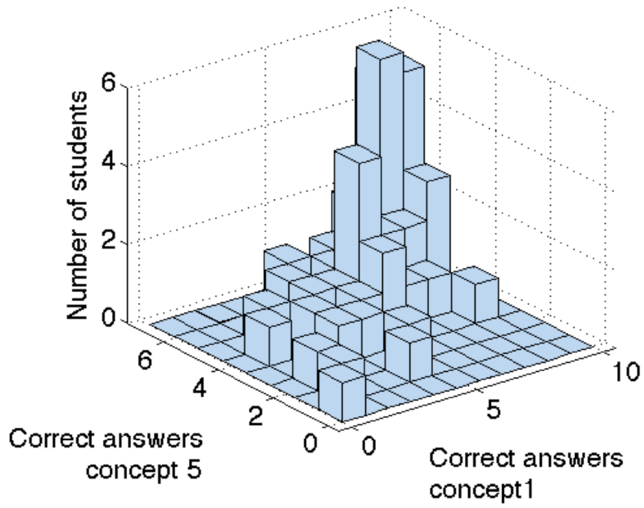

Figure 5.5: Preparation of data in order to calculate the mutual information between the knowledge of two concepts (concept 1: velocity as rate; concept 2: acceleration as rate). The data show the distribution of students with the number of correct answers to concept 1 questions versus the number of correct answers to concept 5 questions.