

# Experimenting from a Distance

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## Remotely Controlled Laboratory (RCL)

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### **Abstract**

The use of computers and multimedia, as well as the internet and new communication technologies, allows for new forms of teaching and learning: distance learning, blended learning, use of virtual libraries, and many more. The herewith discussed RCL project shall offer an additional contribution. The basic idea is for a user to connect via the internet with a computer from place A, to a real experiment carried out in place B. Currently, about 10 RCLs have been implemented (e.g. electron diffraction, diffraction and interference of light). An additional 10 are being built or tested (e.g. radioactivity, measuring the speed of light). The essential characteristics of RCLs are the intuitive use and interactivity (operating the technical parameters), the possibility to choose different points of view of the ongoing experiment thanks to web cams, and the quickest possible transfer of the data measured by the user. A reasonable deployment of sensibly chosen real experiments in RCL allows a new form of home-work and exercises, as well as project work and the execution of experiments, which usually would be a teachers' prerogative only.

### **1. Introduction**

Real experiments are central in the teaching of physics in schools and universities. Moreover, the sensible use of computers (since approx. 1970) and of multimedia (since approx. 1990) has enriched the importance of the experiments: animation of complex procedures (e.g. physical laws in a nuclear power station, astrophysical phenomena), interactive simulation to deepen knowledge (e.g. representation of phase space of a chaotic pendulum) [1], interactive on-screen experiments for self-learning (e.g. electric oscillatory circuits) [2], and measurement videos as an alternative for home-work (e.g. thermal expansion with a Michelson interferometer) [3].

The question is: beyond that, how can the internet be integrated in a meaningful way. There are known examples of lectures video broadcast to different locations [4], of virtual libraries, of databases and education servers being used [5]. In addition, the proportion of distance learning will increase; this poses problems especially for subjects focusing on experiments (physics, chemistry, biology), if it is to be avoided to have only lecture notes distributed electronically [6].

### **Fig. 1**

The concept of the RCL is for a user with a computer from a distant location to remotely control an experiment set up at a specific location (Fig. 1). This principle has been known for years in research and technology, one only has to think about the control of complex conveyer belts in factories or about space telescopes and space probes. When implementing RCLs, it is important that the user is able to follow the real experiment via a web cam, to follow the changes of parameters with another web cam, and to gather the personal measuring data online.

Operating the experiment should be as authentic and transparent as possible for the user, i.e. the experiment should come across as a common real experiment carried out in lessons or in lab courses. To convey this procedure, we have therefore added a playful approach through a maze-robot in RCLs (Fig. 2).

### **Fig. 2**

Further requirements for RCLs are easy access and intuitive operating. Measurements and observations need to be quickly available. Moreover, the user needs to find all necessary information (be it background knowledge and theory, technical specifications of the equipment, etc.) directly in the accompanying text published on the web site, without having to rely on looking it up on other sources.

There is by all means a need for RCLs, though it must be critically observed whether the user operates the RCL to play, to learn, or even to research; more on this later on. So far, we have considered three relevant target groups.

First group: Schools and universities should be given access to a network of RCLs to promote self-learning (for homework and exercises via internet).

Second group: RCLs should allow interested lay people or visitors to exhibitions to further dwell into a subject (e.g. computer tomography).

Third group: the network of RCLs could overcome the problem of lacking experimental labs for educational purposes in particular for students of the so-called third world. To this end, a worldwide network of RCLs offers a positive contribution to globalization.

Since this technology (to manage real experiments over the internet) is not new, several approaches to RCL should exist since the availability of computers (~ 1970) and since the establishment of the internet (~ 1990).

## **2. Worldwide Inventory**

We carried out detailed research at worldwide level in May 2004 and we found roughly 70 RCLs, of which only about 50 were free to access, while some require a user account, some require payment or are only accessible to a close circle of users (incidentally, we in our project reject fees). Only about ten of these RCLs worked flawlessly; all others had either broken links, or the experiment was „out of order“, or it was not a proper RCL in the way we understand it, or the controls did not react. Most experiments referred to either control engineering or games (e.g. moving building blocks with a robotic arm [7]). Fig. 3 presents three examples, which in our opinion are among the best. All in all, this is a disappointing result, considering the potential contained in the combination of internet, physical experiments and technology.

### **Fig. 3**

Obviously, most of the RCLs are related to engineering techniques like steering and controlling (about 90%), only a few percent of efforts to realize remote labs are dealing with physics experiments. Of the various projects we want to mention only two joint projects which are of large scale and of relevance according to our purposes:

- PEARL (Pactical Experimentation by Accessible Remote Learning),
- I-Labs (Internet Assisted Laboratories).

In the PEARL project (duration 2000-2003) four universities cooperated to develop a flexible system enabling students to conduct real-world experiments remotely via the internet [8]. As a key result teaching experiments were provided in the following subject areas: foundation level science – grating spectrometer (Open University, UK), manufacturing engineering – computer vision (Trinity College Dublin, Eire),

electronic engineering - digital electronic workbench (University of Porto, Portugal), and cell biology – electron microscope (University of Dundee, UK).

Three groups (KTH Stockholm, Sweden; Learning Lab Lower Saxony, Hannover, Germany; Stanford University, USA) are working together in the “Wallenburg Global Learning Network” (WGLN) project called I-Labs [9]. Experiments are developed in the areas of fluid mechanics, mechatronics, and physics. Besides development of remote controlled labs didactic concepts and pedagogical issues will be implemented and evaluated.

Most developers underestimate the required efforts and financial resources needed to build and in particular to maintain an RCL. Missing standards (experiment – computer interface, website - control software interface etc.) lead to many individual solutions, and therefore to unnecessary hurdles for hosts and users. Moreover, the focus is currently on technical problems (e.g. various interfaces, programming languages and browser standards, choice of several web cams, data transmission), which leaves little time for the necessary didactical efforts (e.g. to analyze how an RCL can be implemented in different teaching and learning situations).

The following web sites will allow a closer look at the current status of RCLs; they present to some extent a complete listing of RCLs available on a worldwide level:

- <http://telerobot.mech.uwa.edu.au/links.html>
- <http://prolearn-oe.org/bin/view/OE/ExperimentDescriptions>
- [http://www.learninglab.de/i\\_labs/docs/Uebers\\_Fernlabore/uebersicht\\_fernlabore.html](http://www.learninglab.de/i_labs/docs/Uebers_Fernlabore/uebersicht_fernlabore.html) (in German)

### 3. Our Development (2002-2005)

We started in 2002 by building a prototype in Kaiserslautern for the diffraction of electrons on a graphite sheet (electron diffraction tube and CASSY interface of the company Leybold [10, 11]), in order to test, to assess feasibility, and to gather errors and experience. This experiment so central to physics lessons allows one to measure the lattice parameters of graphite by varying the velocity ( $\sim$  wavelength) of electrons which are accelerated by an electric field (Fig. 4).

**Fig. 4**

The user can change the acceleration voltage, measure the diameter of the diffraction rings through web cam (with a scale that needs to be switched on), save them as images, and evaluate the measurements. Option ‘Setup’ in the main menu presents a picture of the experiment, in which each component of the set up is explained; a further option contains background knowledge and the manufacturer’s specifications of the electron tube; option ‘Analysis’ presents a sample evaluation with discussion of measurement errors as well as a list of images to compare previous measurements, so that the user can recognize how the result should look. Questions around the experiment round off the discussion. As for the execution of the real experiment, e.g. a demonstration during lessons, things can go wrong for the user (fluorescence fading in the tube: ageing tube; scale switched on does not fit with the central image: misalignment of the experiment; voltage cannot be increased since it has already reached maximum value: protection of the tube).

With the exclusion of the replacement of a tube, the experiment has now been running without problems for the past three years (see Chapter 5, Initial Experience).

The following RCLs were built, activated and kept constantly tested for about one year for an exhibition at the ‘Deutsches Museum’ in Munich (Autumn 2002 – Autumn 2003 on the topic „Climate“); there were about 20,000 users (see further below):

- Robot in a Maze (Fig. 2),

- Thermal Imaging Camera,
- Optical Tweezers (Fig. 5),
- Fuel Cell.

Herewith we will briefly present the Optical Tweezers RCL; this experiment represents our intention to allow interested lay people to conduct a ‘mini-research’, in this case on the topic of “Telemanipulation with Light”. Tiny glass balls (typical diameter measured in micrometers) are suspended on an object carrier and observed by means of a CCD camera mounted on a microscope with oil immersion lens (the Brownian motion of the spheres is clearly recognizable). In addition, by switching on a laser, a selected sphere can be captured by the laser focus, and moved in relation to the object carrier to a pre-defined position by switching off the laser (Fig. 5).

### Fig. 5

This experiment is a very ambitious RCL alternative, since it utilizes a current research tool from biophysics and genetic engineering. The experience shows that there were no problems with either the tools or the RCL components, but there were some problems preparing and keeping the sample (suitable solution, adhesion of the spheres, etc.).

Three more experiments were realized for physics lessons in 2004, which could be released soon.

- Diffraction and Interference of Light (test phase, access already possible [12], Fig. 6);
- Optical Analogy to a Computer Tomograph [13] (Fig. 7),
- Hot Wire as a prototype for students’ projects with Fischertechnik® construction system [14] (Fig. 7).

„Diffraction and Interference“ is also a central experiment of wave optics (demonstration of the phenomena, model of light as a wave comparing the experiment to a simulation, challenging mathematical derivation of the formula). Usually, building the experiment for demonstration purposes poses a list of problems: laser availability, security concerns, choice of suitable diffraction objects, alignment of the optical path, mainly qualitative implementation in lessons, quantitative evaluations and systematic variations of technical parameters too time consuming.

### Fig. 6

A possible implementation could envisage having the teacher explaining the theory and carrying out a qualitative experiment during lessons; the students are then split into groups and are given the task to carry out the experiment via RCL as homework. Each group is assigned an object to measure and to evaluate (parameter: slit width, slit distance) and knowledge questions to answer. The groups present their results during subsequent lessons as a ‘homework discussion’.

We will further build, test, and release physics experiments over the 2005/2006 period (see Chapter 6, Further Development).

## 4. Didactic Documentation

Different target audiences (interested lay people, pupils, students, and teachers) require different documentation. The web site has been structured on the basis of “Play – Learn – Research” [15] to suit interested lay people; for the use in lessons, we have chosen the usual scheme of “Introduction – Theory – Experiment – Evaluation – Discussion” [16]. In addition, each RCL obviously contains its particular aspects relating to the discussion topic.

It is however our opinion that following elements are indispensable: provision of the physics background knowledge (it cannot be expected that the user interrupts the RCL experiment to retrieve information from

the library), sufficient description of the tools being used (e.g. data sheets from the manufacturers); indirect measurement examples, to enable the user to properly class their own result (e.g. image archive or web cam pictures of previous measurements); evaluation example with discussion of measurement results and measurement errors (e.g. comparison with values from publications, sources of errors) as well as knowledge questions.

Our aims for the final version of our RCLs are for students to be able to use a hands-on RCL alternative, for teachers to read or discuss pre-prepared teaching paths included in the RCL, and for a technical RCL alternative with indications on programming and further development (e.g. in relation to students' projects) to exist.

## **5. Initial Experience**

We receive feedback in different ways, mainly from three target groups: through distance learners ('Früheinstieg ins Physik Studium', FiPS = 'Early Entrance in a Physics Studies' [6]), through participants of in-service teacher training courses, through individual contacts with users at exhibitions. In addition to that, we have installed tracking and monitoring devices in some RCLs; i.e. we are able to capture all relevant data of a user by identifying the IP address and information provided by the user: user name, institution, country, which parameters have been changed in what way (playing or purposeful work), duration of use, and more. This is obviously done in observance of the privacy laws.

It is our intention to expand and improve the tracking and monitoring in future, in order to recognize how well the basic documentation is read (e.g. by following the navigation between pages), when and why a user leaves, and more.

Access rates to RCLs in the Deutsches Museum and in Kaiserslautern have been captured over a period of time (table 1). According to this, RCL experiments are accessed worldwide once to five times a day; this is in comparison to the average teacher who once a year carries out such an experiment during lessons.

**Table I**

The higher financial commitment (compared to the real experiment) includes hardware (interface, computer, web cams) as well as programming costs (typically 1-2 months worth of work per experiment during the initial phase, i.e. until the software modules can be transferred). Higher development costs for some projects can arise due to missing standards and due to necessary re-development (e.g. installing several web cams for an experiment in conflict with operating system). Our RCLs in Kaiserslautern and in the exhibition in the 'Deutsches Museum' are being used in parallel for both visitors (e.g. Optical Tweezers in a lab course for biophysics students) and users via internet. If several users want to access an RCL simultaneously, they are put in a queue and a relevant message is displayed to them.

The maintenance of the real experiment contains usual tasks. However, the maintenance of the experiment computer and of the web server is much more expensive. RCLs are set up to maximize interactivity, exposing their computers to regular attacks from the outside (hackers, viruses, Trojan horses, etc.). Currently, we have solved this problem with the installation of a firewall. However, technical development on both sides continues, both for legitimate usage and abuse.

## **6. Further Development**

We are planning to build 10 further RCLs in the near future (2005-2006), in collaboration with Intel® Germany for their teaching and learning platform [17] and with support from the Eberhard von Kuenheim Foundation (BMW Germany), as well as with the Employers' Association 'Gesamtmetall'. To this end, we have pre-selected approx. 30 experiments from a list of about 300 school experiments of secondary school curriculum, based on the following criteria:

- How central and meaningful is the experiment to the physics lessons?
- What is the priority of the experiment in the lesson plan (not just topic related)?
- What are the difficulties in learning and understanding of the students?
- How difficult or easy is it to carry out the real experiment?
- What interactivity makes sense to offer via RCL?
- How can data be quickly processed?
- How solid is the real experiment, including control over personal computer (maintenance effort)?
- Is the technical effort justified?
- Which media could be implemented concurrently or alternatively?

The following experiments are currently being developed:

- Characteristics of building blocks in electronics (voltage-current diagrams);
- Charging and discharging a capacitor;
- Electric resonant circuits;
- Wind tunnel;
- Radioactivity;
- Lorentz force on electron beam (determination of the ratio  $e/m$ );
- Measuring the speed of light (time-of-flight method);
- Photoelectrical effect (determining the value of Planck's constant).

To describe the above mentioned RCLs in closer detail would go beyond the intentions of this paper. Once we have built and tested the experiments, and established the RCLs, they will be handed over to 'Intel Virtual School' [17] and the supervising teachers will be inducted. A network of RCLs in schools should be the result. Pupils should make use of RCLs not only for demonstration experiments or homework for physics lessons, they should be put in a position to build their own RCL project. Fig. 7 shows two examples of how we picture this alternative with the help of Fischertechnik® components [18]. A first application, "Summer Camp for Pupils" at Munich in 2005 as a workshop to build and set-up RCLs, was very promising.

**Fig. 7**

RCL-experiments in co-operation with universities from European countries and from the so-called third world are currently thriving and in the process of being built. Collaboration with scientific museums is planned, in addition to the 'Deutsches Museum', who will open a section called "Centre for New Technologies" in 2007. Related to this project, a prototype of the Scanning Tunneling Microscope as a RCL is nearly completed.

A worldwide network of RCL clusters should be the long term outcome, offering different RCLs. The advantages are obvious: the maintenance of real experiments is not borne by just one institution; everyone can learn from each others' experiences; synergies can be used to solve technical problems; different cultural approaches to install, implement, and test an RCL in learning environments will exist.

## **7. Conclusions**

- We are trying to increase the use of modern communication technologies and internet for teaching purposes through the RCL project.
- We want to make distance studies more interesting and appealing: move away from paper-based studies, towards internet-based degrees, especially in subjects focusing on experiments.

- There is a need to highlight the importance of real experiments compared to simulations or animations.
- Young people on the internet should be attracted to technology and education in play mode.

## 8. Acknowledgements

As a closing statement, we would like to thank the sponsors of the projects, who have always believed in the potential of RCLs: the Eberhard von Kuenheim Foundation of BMW Germany, represented by Dr. Glaser and Mrs Huber, the Employers' Association Gesamtmetall (Think Ing initiative), represented by Mr Gollub, the Deutsches Museum (Dr. Hauser), and more recently Intel® Germany – Education Group, represented by Dr Martina Roth and Mr Ensle. The collaboration of the Netzmedien Association during the initial stage, represented by Dr Roth and Mr Maus, was extremely important.

## 9. References

- [1] The Physlets® of W. Christian and colleagues are mentioned here, representing many developments in the implementation of simulations and animations in physics lessons: W. Christian, M. Belloni, *Physlet® Physics – Interactive Illustrations, Explorations, and Problems for Introductory Physics* (Pearson Education, Upper Saddle River, NJ, 2004). <http://webphysics.davidson.edu/applets/applets.html>
- [2] J. Kirstein, “Interactive Screen Experiments: Documentation and Presentation of Real Experiments in Physics with Standard Multimedia Technology”, Proc. MPTL 4, November 22-23, 1999, Amsterdam. <http://www.ifpl.tu-berlin.de/> and [http://pen.physik.uni-kl.de/w\\_jodl/MPTL/docs/CONTAMST.pdf](http://pen.physik.uni-kl.de/w_jodl/MPTL/docs/CONTAMST.pdf)
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- [4] In this paper we do not want to discuss whether it makes sense didactically to broadcast lessons over the internet.
- [5] For comparison see the compilation in: S. Altherr, A. Wagner, B. Eckert, H. J. Jodl: “Multimedia material for teaching physics (search, evaluation, and examples)”, Eur. J. Phys. **25**, 7-14 (2004).
- [6] For example, we mention here a multimedia based university physics teaching distance course: early entrance in physics study (“Früheinstieg ins Physikstudium”, FiPS). <http://www.fernstudium-physik.de>
- [7] K. Taylor, B. Dalton, University of Western Australia: <http://telerobot.mech.uwa.edu.au/>
- [8] M. Cooper, A. Donnelly, J. Ferreira, “Remote Controlled Experiments for Teaching over the Internet: A Comparison of Approaches developed in the PEARL Project”, ASCILITE Conf. Proc., Auckland, December 8-11, 2002. See also: <http://iet.open.ac.uk/pearl/>
- [9] Wallenburg Global Learning Network (ed.), “Achievement Report 2003-2004”, pp. 16-18. See also: <http://www.wgln.org> and [http://www.l3s.de/i\\_labs/](http://www.l3s.de/i_labs/)
- [10] Leybold Didactic GmbH. [http://www.leybold-didactic.de/data\\_e/index.html](http://www.leybold-didactic.de/data_e/index.html)

- [11] RCL Electron Diffraction: <http://131.246.237.97/rlab/web/eindex.shtml>
- [12] RCL Diffraction and Interference of Light: <http://131.246.237.56/startseite.html>
- [13] As a first step, we set up a version based on the principle of rear projection (after a suggestion for an analogy: R. Berger, B. Kölbl, H. Wiesner, “Die Röntgen-Computertomographie – eine medizintechnische Anwendung für den Physikunterricht, Praxis der Naturwissenschaften – Physik in der Schule, **48** (4), pp. 44 (1999)). At the same time, an alternative more suitable for secondary school level (e.g. in: B. Eckert, W. Stetzenbach, H. J. Jodl: *LowCost-HighTech* (Aulis Verlag Deubner, Cologne, 2000), pp. 58-59) is preferred and will be implemented at a later stage.
- [14] RCL Hot Wire: <http://131.246.237.59/index.asp>
- [15] “remote\_lab” (Eberhard von Kuehnheim Foundation, BMW Germany): <http://www.remote-lab.de/>
- [16] RCLs at the Technical University Kaiserslautern (AG Jodl): [http://pen.physik.uni-kl.de/w\\_jodl/RCLhome.htm](http://pen.physik.uni-kl.de/w_jodl/RCLhome.htm)
- [17] Intel® Teach to the Future: <http://aufbaukurs.intel-lehren.de/index>
- [18] Fischertechnik® Company: <http://www.fischertechnik.de/english/index.html>



**Table I:** Usage of RCLs

a) at the “Deutsches Museum” as part of an exhibition (evaluation period January – March 2003)

	<b>Total Access</b>	<b>At the museum</b>	<b>Via internet</b>
<b>Optical Tweezers</b>	4509	4115	394
<b>Thermal Imaging Camera</b>	7744	7244	500
<b>Robot in the Maze</b>	5060	4567	493

i.e. about 50 users per experiment a day in the museum, about 5 users per experiment a day via internet.

b) **Electronic Diffraction Tube** in Kaiserslautern via internet

July 2002 - October 2002	2-3 a day
July 2002 - December 2003	1-2 a day
Mid December 2004 - Mid January 2005	4-5 a day

## Figure Captions

**Fig. 1:** Principle of RCL: A user at location A with a client personal computer controls a real experiment at location B via internet. The experiment is controlled by the user through a computer (and simultaneously a web server) over an interface; at least one web cam allows the experiment to be observed.

**Fig. 2:** RCL „Robot in a Maze“: the variable maze and the robot vehicle are seen on the left. Two viewing modes are possible: tilted laboratory view from above (image left) and robot view (web cam placed on the robot). The relatively simple controls of the robot and the status display are visible on the right hand side. A sample task for the user is to find the place in the maze where – in the robot view – one can see the robot itself at a mirror wall.

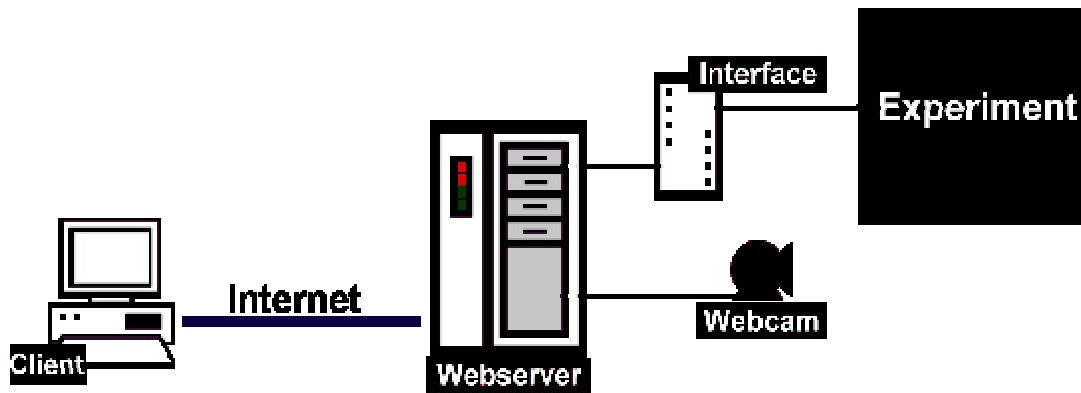
**Fig. 3:** Homepages of worldwide RCLs that we found worth viewing (selection). Above left: Gamma-Ray Spectroscopy (<http://electron5.phys.utk.edu/Gamma/>), above right: Observatory (<http://www4.ellinogermaniki.gr/ep/eudoxos/etool/>), below: Remote Dynamical Systems Laboratory (<http://dynamics.soe.stevens-tech.edu/>).

**Fig. 4:** RCL „Electron Diffraction Tube“: set up of the experiment with CASSY-interface, power supply, electron tube and web cam (top). Part of the website under option „Laboratory“: live video stream (the diffraction order 0 is blocked) as well as chosen acceleration voltage and voluntary user data (bottom).

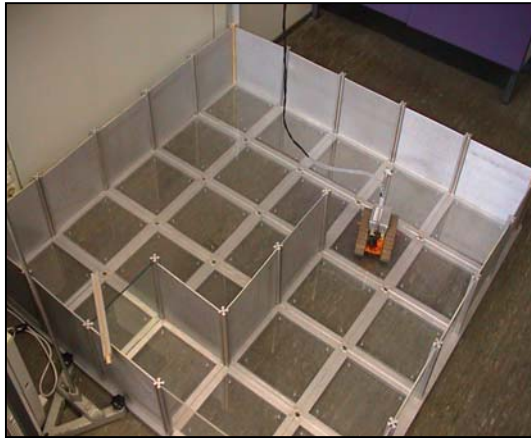
**Fig. 5:** RCL „Optical Tweezers“: simplified scheme (top left) and photo of the experimental set up (top right). The user can switch the laser on and off, align the focus (vertical  $z$ -axis) and move the object carrier and therefore the relative position of the laser focus on the  $x$ - $y$  area. The image below shows a representative still photo of the live video stream of the microscope camera, where the laser has just captured a particle (the height of the image corresponds to ca. 20  $\mu\text{m}$ ).

**Fig. 6:** RCL „Diffraction and Interference“: The user can choose between several single slits, double slits and gratings (top: RCL homepage, currently only in German). One web cam shows the rotary disk, on which the objects are positioned, a second web cam shows the diffraction on the screen (below left). The user can take a picture of the intensity pattern and then store it; following on, with the help of a tool the user can evaluate the intensity distribution and model the result with a Java applet (below right).

**Fig. 7:** Pupils' project: based on the “Intelligent-Interface” by Fischertechnik®, as well as on a special software to control the RCL, pupils can independently build their own robot as an RCL as part of a project for self-defined purposes, e.g. to steer and regulate, as an assembly line robot. The scheme above left shows the idea of the “hot wire”. The image on the right shows the web cam view on the robotic arm of the toy robot as well as the controls in the web page to steer the robotic arm. The user has to move the robotic arm with a wire noose along a wire as quickly as possible, without touching the wire (a green LED is lit, touching the wire causes a short circuit and a red LED is illuminated). The figures below shows the set up and the principle of an optical analogy experiment of X-ray computer tomography, also built with a Fischertechnik® interface.



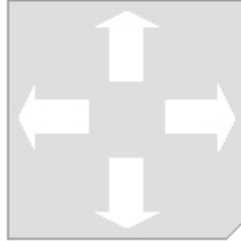
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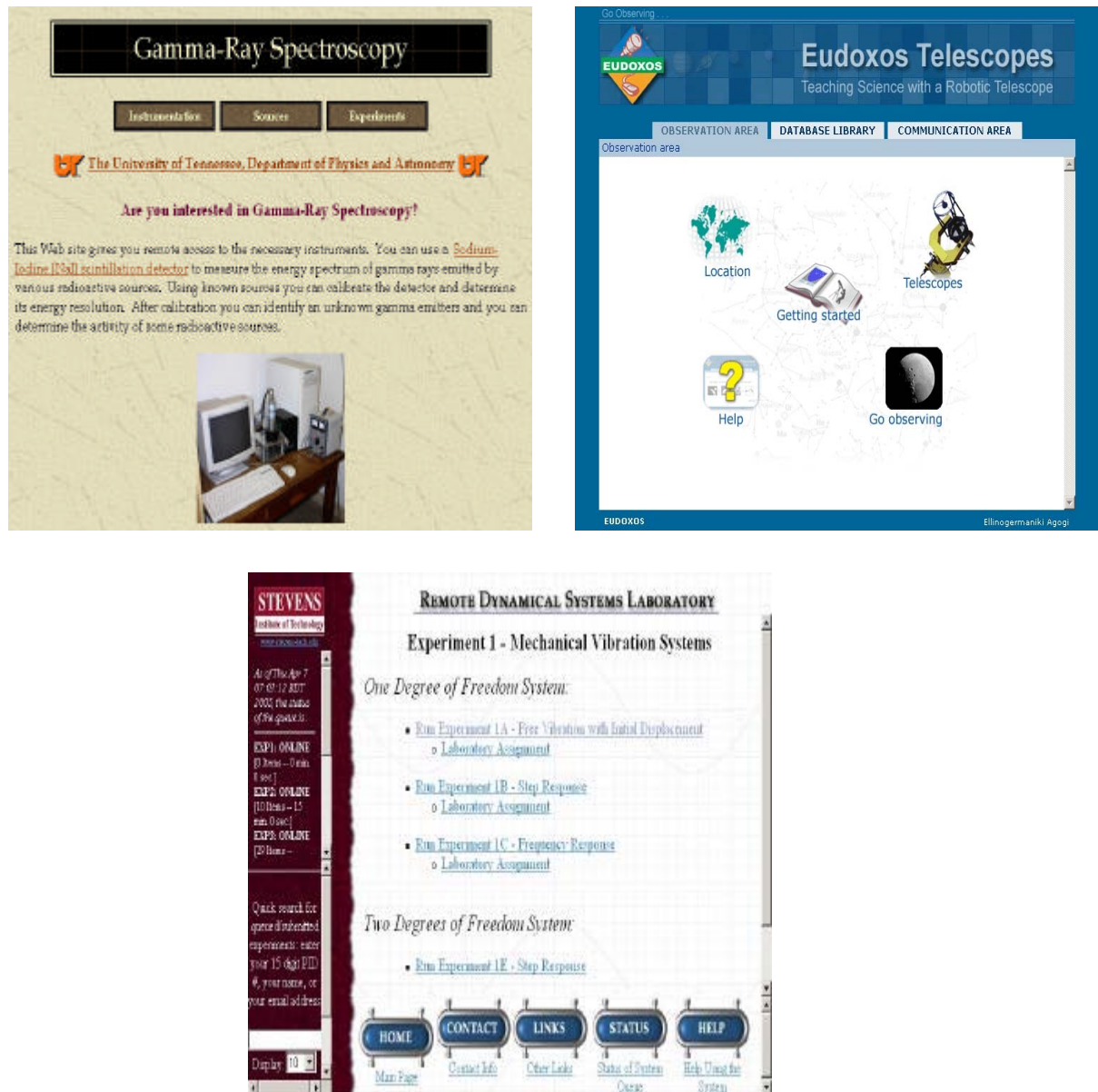
actual user  
**B E from Germany**

current status:

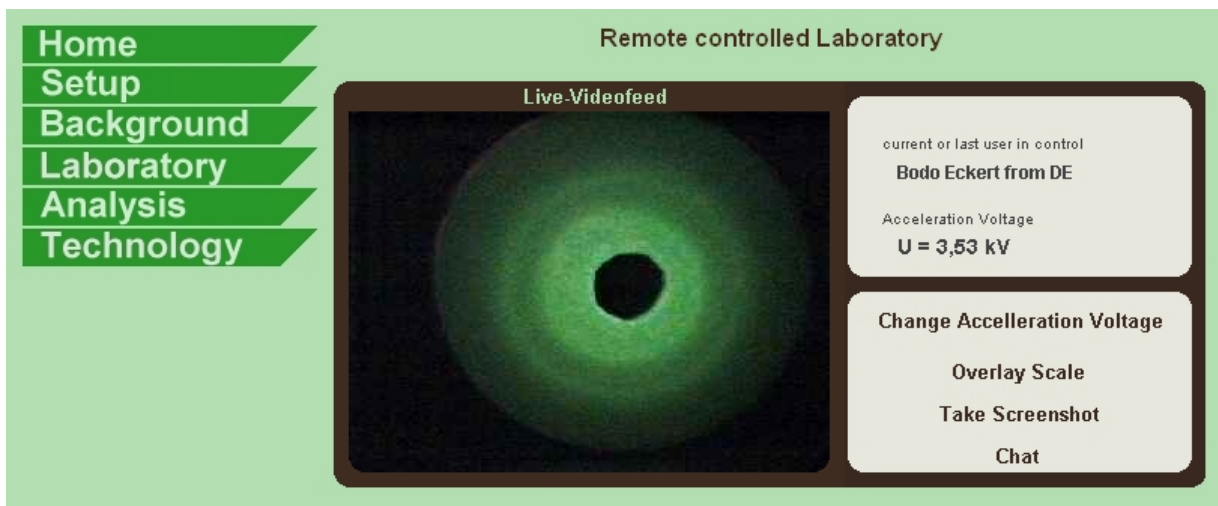
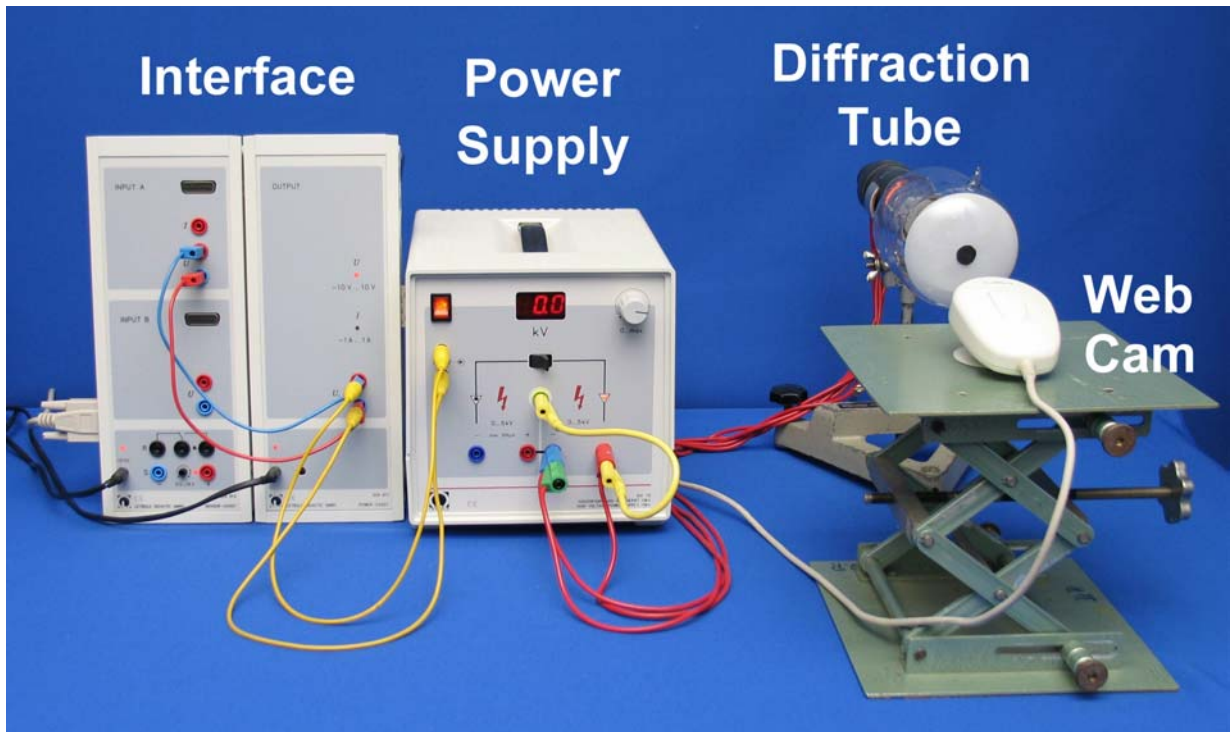
To stay in control take next action in less than 30 seconds. **Exit »**



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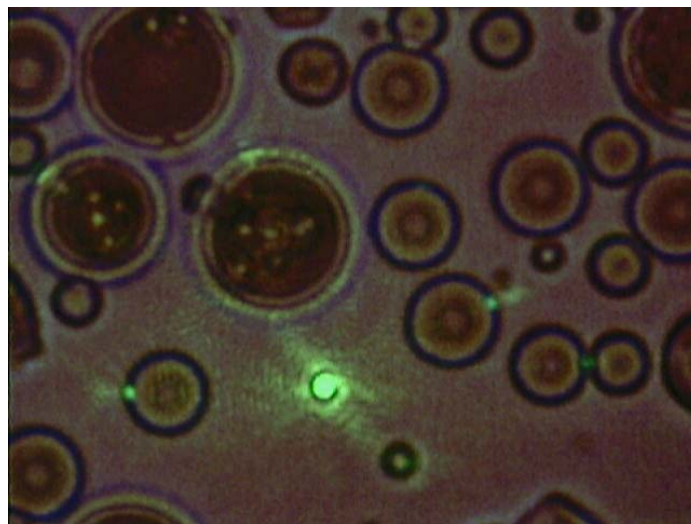
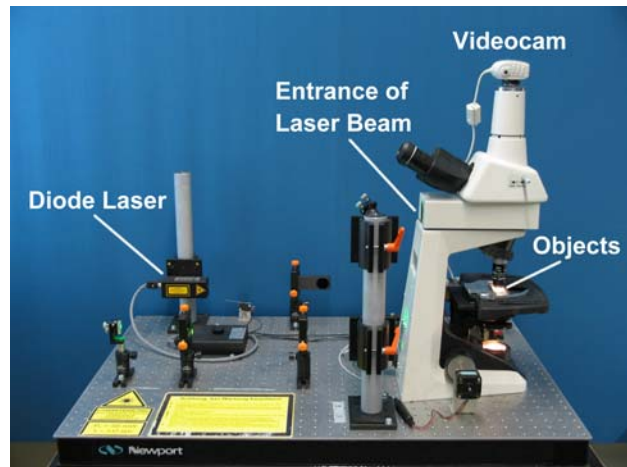
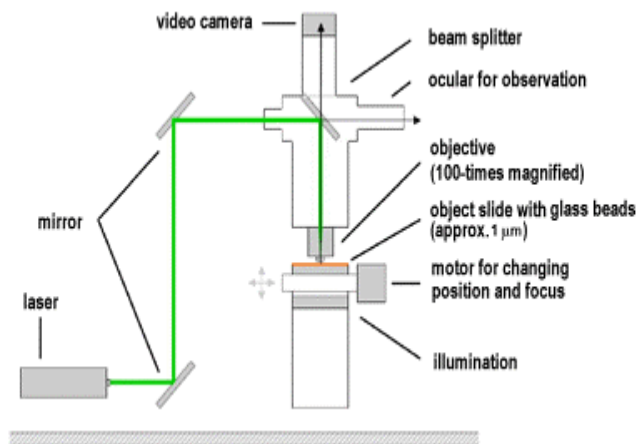


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**Startseite**

**Theorie**

**Einstieg**

**Doppelspalt**

**Einzelspalt**

**Gitter**

**Labor**

**Auswertung**

**Diskussion**

## Einstieg

Unter der Beugung des Lichtes versteht man die Abweichung der Lichtausbreitung von den Gesetzen der geometrischen Optik beim Durchgang durch begrenzende Öffnungen oder beim Vorbeigang an Kanten. Deutlich sichtbar wird die Beugung wenn diese begrenzenden Öffnungen (z.B. Spalte) in der Größenordnung der Wellenlänge des einfallenden Lichtes liegen. Infolge der Beugung kommt es zu sogenannten Interferenzen, d.h. der Überlagerung von Wellen, die sich verstärken (konstruktive Interferenz) oder auslöschen (destruktive Interferenz). Im Labor steht eine Anordnung von Laser (erzeugt kohärentes Licht), Schirm und verschiedenen Spalten bereit. Sie können verschiedene Doppelspalte, einen Einzelspalt und ein Gitter in den Strahlengang des Lasers hineinfahren und die entstehenden Beugungsfiguren auf dem Schirm (1m Abstand vom Beugungsobjekt) mit der Web-Cam beobachten. Beginnen Sie mit der Untersuchung des Doppelspaltes im Labor, indem Sie sich das Beugungsbild mit der Web-Cam anschauen.

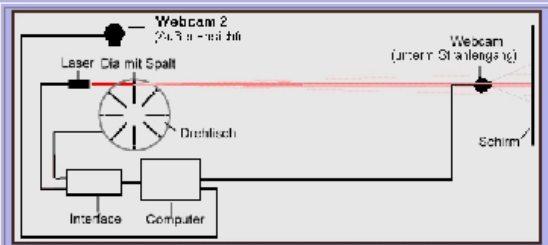
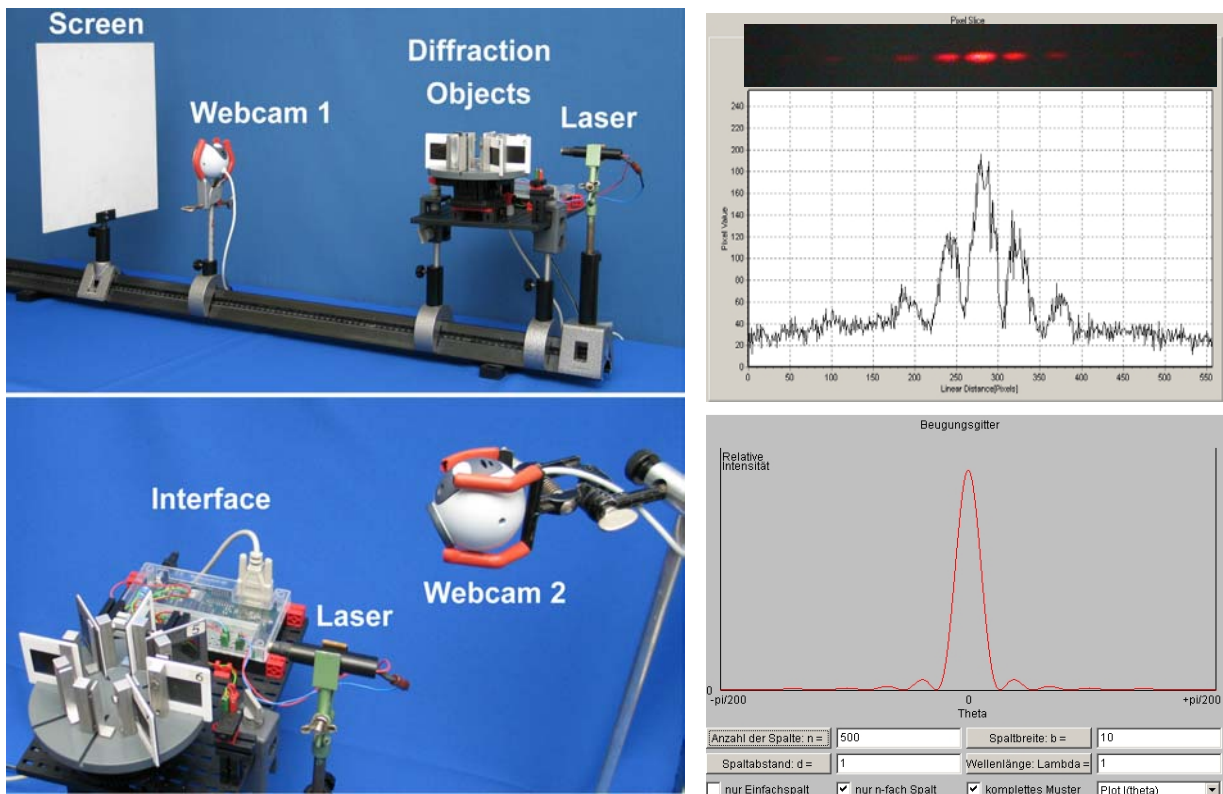
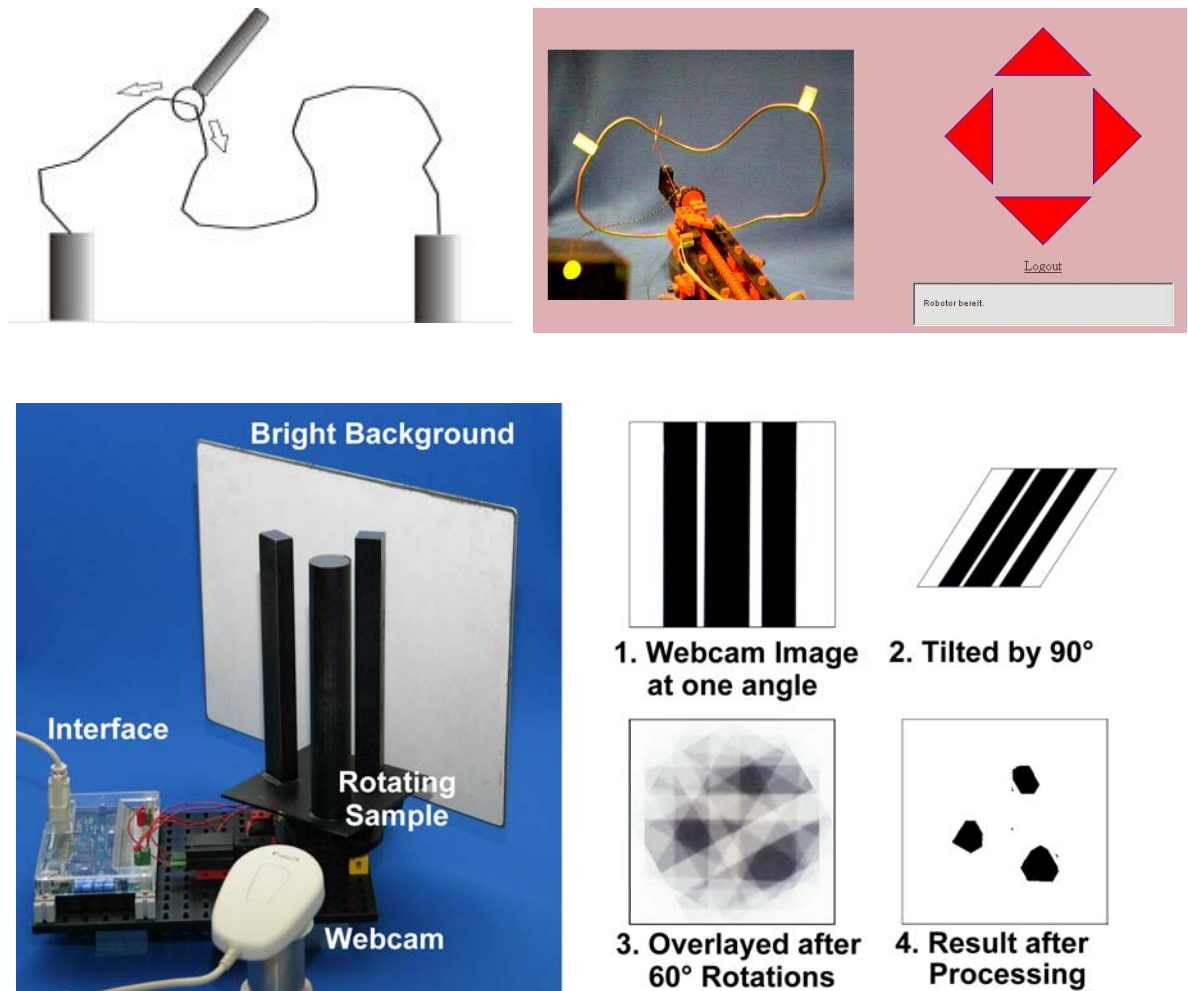


Abb.1: Versuchsaufbau von oben (schematisch)  
(Für größere Ansicht anklicken)



**Fig. 6:** RCL „Diffraction and Interference“: The user can choose between several single slits, double slits and gratings (top: RCL homepage, currently only in German). One web cam shows the rotary disk, on which the objects are positioned, a second web cam shows the diffraction on the screen (below left). The user can take a picture of the intensity pattern and then store it; following on, with the help of a tool the user can evaluate the intensity distribution and model the result with a Java applet (below right).





**Fig. 7:** Pupils' project: based on the "Intelligent-Interface" by Fischertechnik®, as well as on a special software to control the RCL, pupils can independently build their own robot as an RCL as part of a project for self-defined purposes, e.g. to steer and regulate, as an assembly line robot. The scheme above left shows the idea of the "hot wire". The image on the right shows the web cam view on the robotic arm of the toy robot as well as the controls in the web page to steer the robotic arm. The user has to move the robotic arm with a wire noose along a wire as quickly as possible, without touching the wire (a green LED is lit, touching the wire causes a short circuit and a red LED is illuminated). The figures below shows the set up and the principle of an optical analogy experiment of X-ray computer tomography, also built with a Fischertechnik® interface.