Multimedia Material for Teaching and Learning Physics

Stefan Altherr, Bodo Eckert, Hans Jörg Jodl[1], Technical University of Kaiserslautern, Department of Physics, Erwin-Schrödinger-Straße, 67663 Kaiserslautern, Germany

1. Multimedia in Physics Education

Multimedia elements are of increasing importance in physics teaching. Phenomena can be presented vividly and correlations can be examined and analysed. In addition, it is possible to simulate complicated content, to present simultaneously different levels of abstraction and to help students gain a better understanding. Videos are widespread as are interactive screen experiments (ISE), computer generated simulations and animations. Screening the internet, more than 5000 multimedia items for teaching physics can be found.

Although a lot of material - commercial as well as public - is available, it is often difficult to find media matching the teaching purpose required at the time. Very often MM (Multimedia Material) found in thematic databases is only described by documentation lacking any further information about its quality for a possible user.

2. Databases

During the last few years the process of searching for MM has been enormously improved by the organization and maintenance of collections of hyperlinks and multimedia servers. Link lists offer huge, mostly thematically sorted registers. These links lead to sites where in most cases only a small number of mediocre material exists. On the other hand, servers provide material directly for downloading.

The quality and quantity of media differ enormously. Therefore, we present a set of web pages that seem to be representative, up-to-date and comprehensive. They are presented in alphabetical order:

- **FiPS – Medienserver [1]**
  This German server contains more than 270 MM items. Most of them are free for use, and only a few require a user account. Primarily, the content covers the topics mechanics, thermodynamics, electrodynamics and optics for the first year of introductory major physics (university level). The material consists of videos, simulations, animations, interactive screen experiments and remote controlled laboratories. It is a mixture of older material, that was subsequently digitized, and more recent developments. The search engine uses keywords, and the content can be sorted thematically. In general, the approved media are of good quality, but there is no kind of integrated evaluation.

- **Leonardo: Interactive Virtual Science Museum [2]**
  This Italian collection of applets delivers a wide range of material in both number and content. The collected media vary greatly in quality and target group. Because of the missing search options and lack of content description it is quite difficult to find the correct item for a possible user. The collected material covers a range from standard physics to rather uncommon life sciences.

- **Merlot – The Multimedia Educational Resource for Learning and Online Teaching [3]**
  This huge archive of links is maintained by the California State University and gives access to sources all over the internet. All media are described in detail and evaluated for easy usage. This database utilizes a sophisticated search engine. The large amount of data, collected for each medium, is disclosed to all users. Most of the content belongs to the category of '*Science and*

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[1] During 1974-84 I meet Prof. A Loria almost every year at the spring meeting of the DPG-FD in Giessen. Alongside the conference we had productive discussions about physics, about education in physics and about our two countries. I will miss him.

Technology'. The main types of media are hypertext structures and simulations. The so-called '*Physlets*' cover most standard topics in general physics.

- **Physlets Ressource Page [4], [5]**
  This collection is run by Davidson College in North Carolina (USA). It offers a huge number of applets with topics in physics only, for school and university level. Content covered, includes simple mechanical experiments (e.g. projectile motion) up to quantum-mechanical presentations. There exist several thousand Physlets worldwide, which are partly categorised here. Quality ranges from very good examples to simple programming exercises with rather less value. Due to the large number of applets, one can always find a suitable example for one's needs in a teaching situation. The German counterpart of this page contains a worldwide search engine and so-called "Physlet-Scriptors" to build up own Physlets without programming knowledge.

- **Teachers´ Page Physics [6]**
  This German collection of links is the most colourful page dealing with multimedia in physics education. It distinguishes nearly 20 main categories from classical physics to more unusual topics. Each category contains more than 100 links to multimedia sources. The quality of these linked pages differ greatly. There is no search engine and only insufficient sorting. Nevertheless, very good media can often be found when using this page as a starting point.

3. Quality and Quantity

In 2002 a working group (WG5), established by the European Physics Education Network (EUPEN), gave an overview of MM available for teaching quantum physics at the European workshop for the use of MM in Physics Teaching and Learning at Parma [7]. The members concluded that due to technical problems approximately 40% of the examined material did not work, and 80% of the media addressed standard topics using simulations / animations and hypertext, respectively. Most of the material only used some possibilities of multimedia technique in minor form and did not try to utilize the full potential of multimedia.
In September 2003 at the European workshop in Prague [8] the same group examined MM for teaching optics. While there were less technical problems there was an even stronger concentration on standard topics such as 'Young's Double Slit' experiment or basic applications on optical benches, for example.
This year, the annual meeting is held at Graz [9] and the group examines MM for teaching mechanics. First results indicate that all things considered, the multimedia elements are of good quality and there are only a few poorly realised examples. Still, standard topics are addressed in most cases.

In our opinion, this leads to several conclusions. First, the quality of most available MM is mediocre or worse (while the quality we found got better each year). Second, only a few media are valuable, but those are difficult to locate. Third, most MM is just described and little is evaluated by more or less "private" evaluation criteria. Therefore we had a closer look at which evaluation methods are available.

4. Lists of Criteria

While searching criteria for evaluating multimedia material, many individual approaches and solutions can be found; e.g. in Germany we identified about 40 such approaches. But often neither the author nor the source is traceable (copyright responsibilities) and the date of publication is not mentioned. There are two groups of publications worth examining more closely. First, there are servers on the internet which are maintained by scientific projects, national or international awards or specific foundations. The second source is publications in journals or books.

In the following we compile a representative list of different approaches for reliable sources only (those having an official status):

- **EASA – European Academic Software Award [10]**
  This biennial competition for developers of academic software is organised by the European Knowledge Media Association. The evaluation scheme defines 'general criteria', 'evaluation criteria' and 'language criteria'. General aspects cover formalities (mostly technical), relevance and innovation. Evaluation aspects range from design and portability to pedagogy and research. Finally, the medium should be in English (or easily translated). In general, the evaluation emphasizes technical aspects.

- **EUPEN – European Physics Education Network [7]**
  In 2002 the '7th Workshop on Multimedia in Physics Teaching and Learning of the European Physical Society' was held at Parma. In the electronic proceedings, recommendations were formulated for MM on quantum physics and for evaluation criteria: 16 points were arranged in four groups concerning demands on multimedia material, aspects of content, teaching and technique. The authors emphasized that a list of criteria should be reasonable and feasible, and considered the initiative to be a starting point for an international discussion of experts. (Reference to the series of European workshops [11])

- **medida-prix [12]**
  The "Gesellschaft für Medien in der Wissenschaft" (Association for Media in Science) organizes a competition for media projects with didactical aims each year. Evaluation takes place in three steps: so-called 'K.O.-criteria' include innovation and correctness of content. 'Product-oriented criteria' deal with the didactical approach, motivation and user friendliness. Finally, 'process-oriented criteria' like modularity and sustainability are judged. The evaluation follows a standardized system, which estimates how far the postulated criteria are fulfilled by a given product.

- **Merlot – The Multimedia Educational Resource for Learning and Online Teaching [3]**
  This archive (see section 2) utilizes a detailed list of about 25 standardized criteria. Three different categories are used: The group of individual criteria 'quality of content' covers correctness and relevance. 'Potential effectiveness as a teaching-learning tool' evaluates learning aims, target group and effectiveness of the medium. In the category 'ease of use' layout and usability are judged. The evaluation procedure for a given product is performed by independent referees, using grades and free text.

- **SODIS-Database [13]**
  SODIS is a consortium of media institutes of the federal states of Germany, Austria and others. This group defined an enormous list of about 65 criteria for evaluating MM. The main categories are 'professional and didactical aspects', 'media-didactical aspects', and 'technical aspects'. Each category is split up into four to six points with up to eleven questions each.

Our investigation shows, that there already exists a large amount of different lists of criteria, each with its own strengths and weaknesses. A systematic comparison of all these lists leads to the conclusion that they mostly follow the same scheme:

- criteria of content
- criteria of didactics
- criteria of method
- criteria of technical aspects

Since this classification pattern mirrors the scientific concept of “didactic of physics”, it is easy to use and obviously to understand. Each point - an individual criterion - is indirectly defined by several specific questions. In general, these lists were developed more from a theoretical point of view than from the practical point of view of a potential user.

5. Problems

It was not our aim to reinvent the wheel nor to set up our own new list of criteria. But the following list of problems, which we encountered working with existing evaluation schemes, were too overwhelming to be satisfied. In addition, we plan to start a discussion within the community on that topic with the aim of proposing a list of criteria which is standardised and agreed by the majority.

- Most of these lists in literature cover all the main aspects but are very often too bulky and thus not very useful.
- Very often such a list has only one specific user in mind; either a referee or a potential user (teacher) or producer of new material.
- Types of multimedia are videos, animations, simulations etc. Some lists consider only a specific type. A criterion “interactivity” is irrelevant for videos or animations.
- Most lists of criteria are developed on the basis of theoretical considerations (academic); therefore they are limited in practicability (amount of time to evaluate, precise questions, limited number of criteria etc).
- Sometimes individual criteria are not disjunctive. For example the aesthetic design is evaluated in the category motivation, as well as in the categories “layout” or” technical realisation”.
- Descriptive and evaluative criteria are not separated; e.g. the type of a medium (video etc.) is descriptive whereas the choice of this type is important for evaluation.
- Sometimes there are questions to compare media with each other while evaluating one specific example. This comparison should not be done within the evaluation, whereas the evaluation of similar products should deliver an objective comparison.
- Finally, very often the questions - describing one criterion - are to general or misleading, so the referee does not know what to do.

On the basis of these problems we will present a new list of criteria, which was already revised within WG 5 of EUPEN [14]. The following list is an attempt to present a complete yet manageable, feasible, flexible and pragmatic set of criteria, which minimizes the problems mentioned above. This list is aimed at evaluating single multimedia products and not a complete learning environment.

6. A New List of Criteria

In the past, our group evaluated at least several hundred products. During that work we recognised three major steps in the evaluation procedure: the first one covers the question of whether a possible user has access to MM, and if the product is motivating enough to have a closer look. If working with the MM, the content has to be checked next. Finally, apart from content and motivation, the product should be examined with regard to teaching implementation, methods and teaching environment (see table 1).

motivation	**content**	**method**
• user-friendliness • attractiveness • clear description of purpose and work assignment	• relevance • scope • correctness	• flexibility • matching the target group • realization • documentation

Tab. 1: New list of criteria

These ten points are

further characterised by several central questions.

User-friendliness: Is it easy to start using the MM? Are the design comprehensible and the image quality satisfactory? Is the function of control elements evident? Are the software requirements clear and of adequate proportion? Attractiveness: Is the layout appealing? Is there a motivating introduction? Are there interactive components? Is the topic interesting (reference to everyday life, applications, explaining a phenomenon)? Is the MM up-to-date / innovative? Clear description of purpose and work assignment: Is the intention of the MM evident? Does the user know what is expected from him? Is there a problem to solve or a context to understand?
Relevance: Is the topic important? Does it make sense to use the MM (e.g. problems in understanding, dynamic process)? Scope: Is there a profoundness of content? Is there a broadness of content (special case, general overview)? Correctness: Is the content of the MM correct? Are simplifications indicated?
Flexibility: Is the MM appropriate for a broad target group (incl. self-learning)? Is it possible to use the MM in different teaching and learning situations? Does the MM allow for the same topic to be approached in different ways? Matching the target group: Is a reasonable didactical reduction implemented? Are technical terms explained? Are the objectives appropriate? Realization: Is the general approach suitable to present the subject and realize aims of the given MM? Is the type of MM chosen reasonable (video, simulation, animation)? Documentation: Is the operation obvious or explained? Is the material self-evident or explained by additional text? Is there a reference to material for further studies? Are there any suggestions for implementation into the teaching process?

Tab. 2: Detailed questions to characterize the criteria

7. Examples: Video and ISE for Teaching Physics

To give the reader more insight of how to evaluate MM using the list of criteria (see table 2), we will first present two media and then apply it to them. We have chosen two of our own recent examples. The first one is a video about diffraction: the so called ‘Rayleigh criterion: the resolution of optical instruments’ is demonstrated while reducing the instrumental aperture. The second one is an interactive screen experiment on the Michelson interferometer, to determine the wavelength of the laser used. Both MM can be viewed on the internet [15].

The video starts in describing the setup with the realization of the sources of the light. Two holes with a diameter of 200 µm at a distance of 500 µm are illuminated by a strong halogen lamp, focussed by a lens. The light sources are observed through a telescope at a distance of 8 m. In front of it an adjustable aperture is positioned.

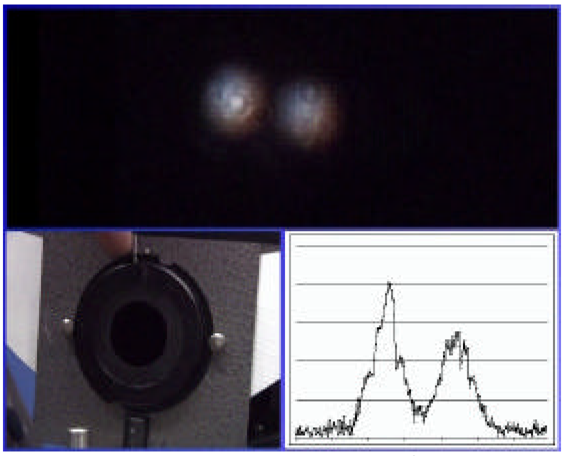


Fig. 1: Rayleigh criterion: the resolution of optical instruments. Top: the two illuminated holes, well separated. Bottom left: the variable aperture. Bottom right: the intensity pattern of the two light sources.

In the following experimentation the screen is split into three areas (see figure 1). In the upper half of the screen the view through the telescope is shown. At the beginning the two light sources can be separated easily, since the aperture is relatively large. In the lower left part the adjustable aperture is shown. In the lower right part the current intensity distribution of the light sources is shown along a central cut.
Next, the aperture is gradually closed. It can be seen, that the diameter of the light points increases (upper part of figure 1) as well as the width of the peaks in the intensity profile (lower part of figure 1). As we get closer to the Rayleigh limit, the two light spots start to merge. Finally, they can no longer be separated and only a single light spot can be recognized. The aim of this video is to show that the user varies a technical parameter, collects and analyses data and compares his or her results with the theory.

Figure 2 presents the experimental set-up of the ISE. In the central part of the picture one can recognise the laser, the Michelson interferometer and behind it the screen. The inset in the top left shows the interference fringes, and the inset at the top right depicts the micrometer-screw with a scale. The experiment is performed such that one rotates the micrometer-screw (from 0 to 4430 nm) i.e. the moveable mirror is shifted by this distance. As a consequence, one registers the interference pattern being generated in the centre of the screen (moving outwards), the number of which must be counted. By means of this measurement the wavelength of the laser used in this set-up can be determined.

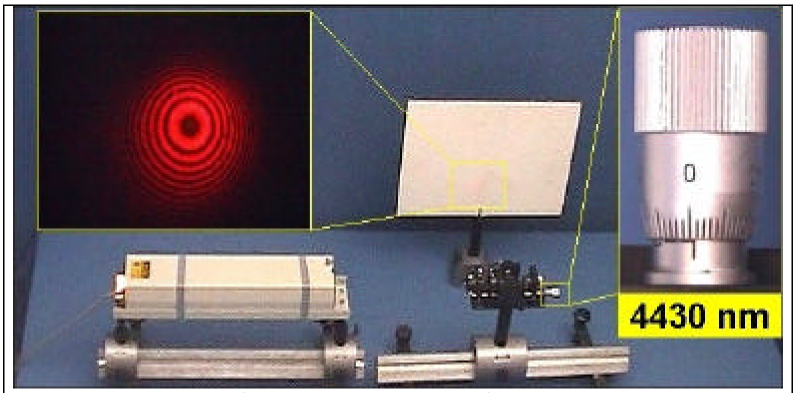
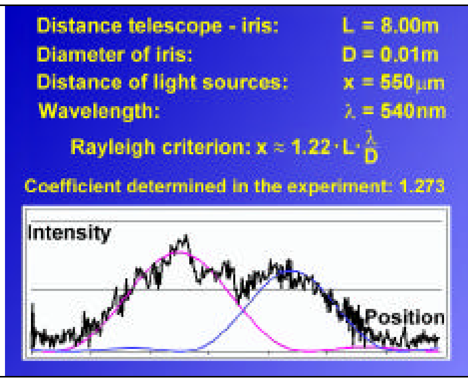
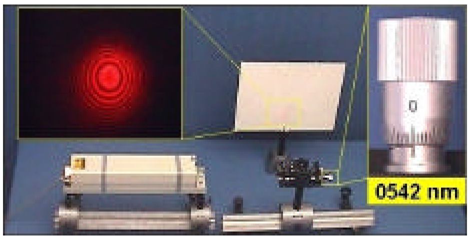


Fig. 2: Michelson-Interferometer: Determining of a Wavelength

8. Applying the New List of Criteria

Now we want to evaluate the two media using the new list of criteria. We use grades from ++ (very good fulfilment of the criteria) to -- (poor fulfilment).
Prior to the evaluation some descriptive data are presented.

This evaluation gives quite good grades to the video. The obvious strong points are the interesting content concerning the target group and the overall quality of the implementation. Negative points are the documentation as well as the limited flexibility.
The ISE is clearly less attractive than the video. Its scope is quite limited. It is an example of mediocre quality.

Descriptive data:		
Name:	Rayleigh-Criterion: Resolution of Optical Instruments	Michelson-Interferometer: Determining the Wavelength of Light
Type:	Video	ISE
Author:	Technical University of Kaiserslautern, Group Jodl	Technical University of Kaiserslautern, Group Jodl
Year:	2002	2002
Screenshot:		
Evaluation:		
Motivation:		
User-friendliness:	+	+
Attractiveness:	+	-
Clear description of purpose and work assignment:	+	+
Content:		
Relevance:	++	+
Scope:	+	-
Correctness :	++	++
Method :		
Flexibility :	0	0
Matching the target group:	++	+
Realisation:	+	+
Documentation:	-	0

9. Remote Controlled Laboratories

In addition to meanwhile well established types of multimedia, Remote Controlled Laboratories (RCL) are the latest development. First examples emerged in the late 1990s, finally getting attention in the new millennium.

Those first examples are solely individual solutions, i.e. constructions which did not utilize any standardized components in hard- or software.

Thus, everyone building its own RCL had to start from the very basics; to find a applicable interface to control the set-up and to program a special piece of software.

Such an example is the “Telerobot” [16] from the University of Western Australia (see figure 3). This robot allows to move wooden bricks on a grid. As one can easily deduce by looking at the robot used or the software programmed, that enormous costs are required building and maintaining the RCL. Regrettably, only little didactical value can be found here.

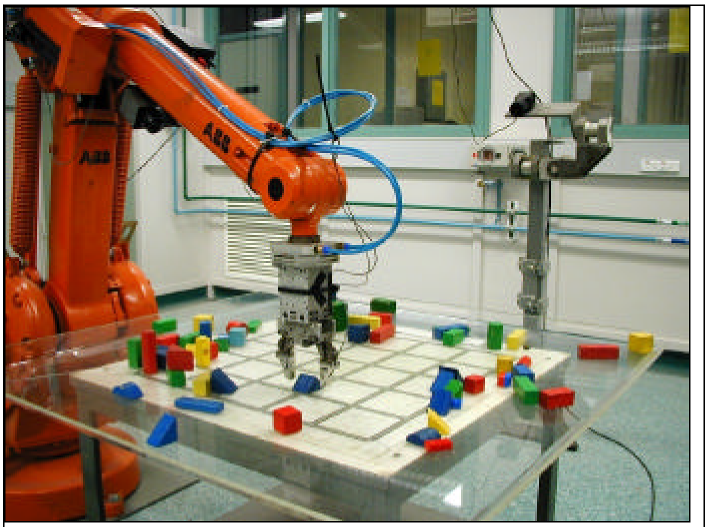


Fig. 3: Telerobot [16]

In general, most developers are still dealing with mostly technical difficulties. This is one reason for the great ratio of RCL with only small didactical aims. Users, who want to build their own RCL, find nearly no technical information.

In addition, the aims and target groups of the RCL are manifold. Possible users are interested non-professionals, pupils, students and others. The intentions range from interesting users in natural sciences and autonomous studies to creating a world-wide learning community [17].

Further examples of individual solutions include the Gamma-Ray Spectroscopy Lab from the University of Tennessee [18] and Eudoxos Telescopes, an observatory that teaches science with a robotic telescope [19].

An approach to solve the problem of non-standard equipment is the introduction of standardized hard- and software. Therefore, in 2002 we started utilizing the CASSY-Interface from Leybold-Didactic [20] which is widespread in Germany. First, we built an experiment on the diffraction of electrons [21]. This installation allows variation of the acceleration voltage. The diameter of the diffraction rings can be determined and thus the atomic layer distance can be calculated (see Fig. 4).

Building-up on this set-up, three further RCL were constructed using the same technique, in cooperation with the Deutsches Museum [22], and Netzmedien GbR [23]. These are a remote-controlled robot, an infrared camera and optical tweezers [24].

All three RCL use the same hardware-interface, and a software prototype that is adapted to fit each set-up.

Another example of such an RCL can be found at Leybold-Didactic itself [25]. Here, an experiment demonstrates the deflection of an electron beam in an electromagnetic field. Parameters that can be varied are acceleration voltage, deflection voltage and the Helmholtz coil current.

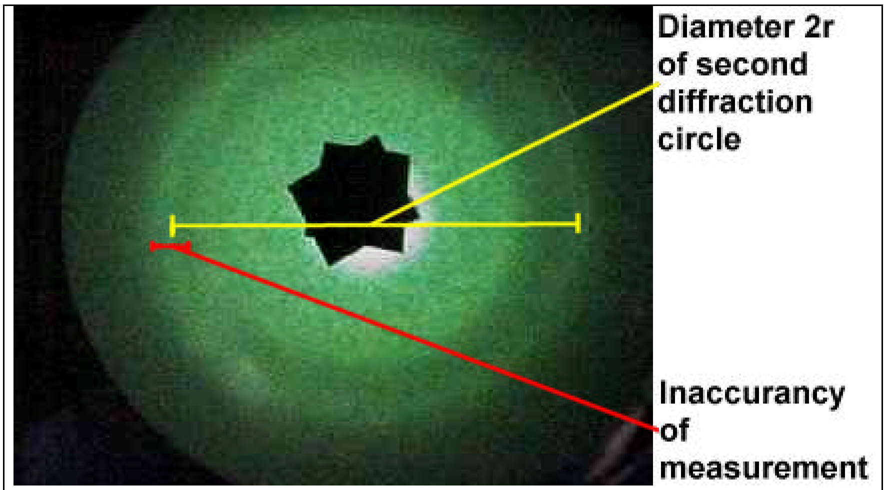


Fig. 4: Diffraction of electrons.

During one year the RCL at the Deutsches Museum have been accessed by 3500 user through the internet and over 50.000 visitors of the museum. These numbers strengthen the need for stable and easily maintainable set-ups, and are thus another argument for using a well established interface.

The many functions of the CASSY-interface result in a heavy price tag that cannot be justified for setting up simple experiments. Because of that, we searched for a cheaper interface with accordingly less functions. We found the Intelligent-Interface from Fischertechnik [26].

The software development for connecting this interface to the internet is nearly finished and will be available soon. A simple test-robot is online for 6 months now (see Fig. 5), and an experiment about double-slit diffraction will go online soon [27].

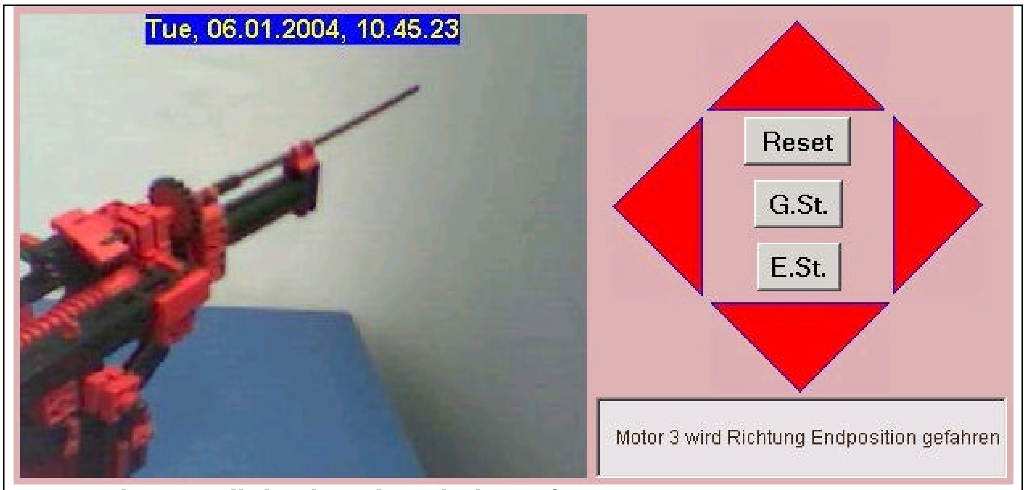


Fig. 5: Robot controlled with Fischertechnik-Interface

Thus, we now have a powerful interface to set-up complex RCL as well as a more simple and cheaper solution that could also be very interesting for schools.
We plan to initiate several projects together with schools starting from one-time RCL workshops up to RCL networks (i.e. linking weather stations all over Europe).

10. Conclusion

The increasing importance as well as the increasing demand on multimedia material for teaching physics is undeniable. On the other hand, many databases in the internet provide a lot of links to multimedia material. But these examples strongly vary in quality. Despite a few attempts to evaluate these multimedia material many lists of evaluation criteria suffer - in our opinion - from fundamental problems.
Therefore, a new list of criteria is presented, which tries to minimise those problems. With this new list we want to stimulate a discussion on a standardised evaluation procedure. This list we provide is reasonable, feasible and easy to be used. In addition, we describe two new multimedia examples: one to demonstrate the Rayleigh limit of resolution (video), the other one demonstrates an application of interference of light (ISE).
The recent developments regarding RCL show a trend away from unique solutions towards standardized equipment. Thus, there is a greater focus on content instead of technique.
The next big step concerning RCL would be to establish a central platform for collecting and evaluating as well as to give support for the set-up of new experiments.

11. Acknowledgement

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