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Letters and Comments

A new medium for physics teaching: results of a worldwide study of remotely controlled laboratories (RCLs)

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Abstract
We report on the results of a worldwide research project on remotely controlled laboratories (RCLs). The findings are briefly commented on and critically reviewed. The survey of RCLs, together with the criteria of evaluation, can be downloaded.

(Some figures may appear in colour only in the online journal)

It is indisputable that physics teaching needs real experiments. But quite often a teacher cannot perform a selected experiment because the equipment is not available or the apparatus is not working, because the experimentation will take too much time or because of safety concerns. As a consequence this experiment may be skipped or it may be replaced by a simulation or by the presentation of a video; or the teacher decides to make use of a remotely controlled experiment. This kind of experiment is a real experiment located at a place A which can be remotely controlled via the Internet by a computer located at a different place B. In the course of a respective project (2001–2011), we reviewed several times what is available worldwide with respect to remote experimentation in science education. In 2010, we found at least 335 items. These RCLs are documented and described by means of about 30 types of metadata such as author(s), institute, topic/subject, year, suitability for teaching, didactical material, web site (URL), language, or administrative characteristics like registration. The complete collection, together with the evaluation, can be downloaded for free[1].

In our own project we set up about 20 RCLs for teaching physics (see footnote 1). The concept, features and technical details of our RCLs, as well as experiences of using those experiments in practice, have been already published through two general articles [1, 2]. Figure 1 shows the distribution of topics of RCLs in the teaching of engineering and of physics; only a few (<5) remote labs for teaching chemistry and biology could be identified during the

[1] Call up the website http://rcl-physics.de/, then choose English language and then in the menu bar 'RCL-Project'.

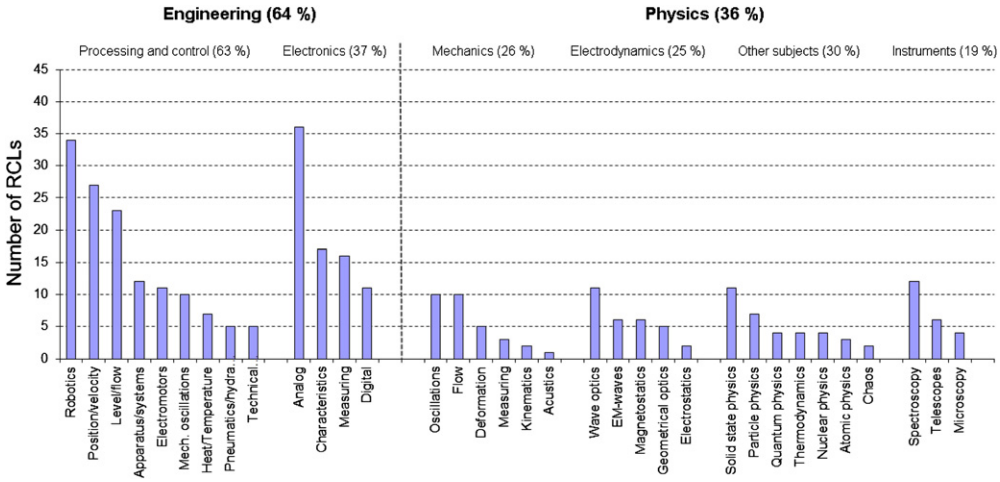

Figure 1. Numbers and topics of RCLs in engineering and physics education.

search. The majority of RCLs can be found in the teaching of engineering, in particular in the field of processing and control. This result is not surprising since topics like processing and control have been used for decades in industry. An area like electronics, on the other hand, is obvious and easy to implement in an RCL architecture (for example, see figure 2 of [3]).

Remote experiments for physics teaching cover mostly mechanics and electrodynamics. Therefore, new RCLs—worthwhile to be developed—should cover mainly the subjects of modern physics. Apart from varying qualities of individual RCLs, we found that providers or developers of remote experiments tried to 'reinvent the wheel': 17 RCLs deal with controlling the level and flow between tanks filled with water, 16 RCLs deal with the characteristics of electronic components, five RCLs deal with an inverted pendulum, four RCLs aim to determine the speed of light, four RCLs deal with the diffraction and interference of light, four offer handling with an oscilloscope, four RCLs deal with interferometry, and finally, four RCLs represent weather stations.

We carefully analysed each single RCL and RCL project using obvious evaluation criteria. The criteria can be divided in two categories: educational (or didactical) and technical issues. Didactical criteria are as follows.

(1) Is this RCL useful in teaching at a certain school or university level?
(2) Is this RCL embedded in a certain teaching environment?
(3) Does this RCL reflect only the lab or is it described by an accompanying webpage, etc.

Technical criteria are as follows.

(1) Is a registration required or is it necessary to apply for some kind of guest account?
(2) Is the RCL restricted to a special group of users such as students of a certain department, for example?
(3) Are personal data required to access the RCL?
(4) Is there any booking system available?
(5) Is the web address easy to find by a simple search (using engines like that provided by Google) or does the hyperlink work?
(6) Does it need long time to load the web pages?
(7) Is additional software like LabView or any strange plug-in needed to run the RCL?
(8) Is the actual state of the RCL displayed?

Table 1. Obstacles which limit the use of the RCLs (see text for reading the columns).

	1	2	3	4	5	6	7	8	8	10	11
Didactical material available, at least setup and theory										x	x
No registration needed									x		x
No java runtime environment (JRE) or long loading times								x			x
No additional software like LabVIEW or non-standard plug-ins necessary							x				x
No booking system						x					x
User group not restricted					x						x
URL of remote experiment was easy to find				x							x
At least laboratory page in English language			x								x
Hyperlink to experiment is working[a]		x	x	x	x	x	x	x	x	x	x
Website exists beside publication in journals or proceedings	x	x	x	x	x	x	x	x	x	x	x
Number of RCLs (% of total)	177 (53)	91 (27)	90 (27)	86 (25)	73 (22)	71 (21)	59 (18)	55 (16)	45 (13)	38 (11)	18 (5)

[a] The number of RCLs belonging to this item may have changed in the last two to three years.

As a final outcome we defined the characteristics of obstacles to using the RCL (table 1), since we are convinced that a user will not carry on the experiment if he or she encounters any barrier.

From column 1 we see that only 53% of all RCLs have a web page allowing access to the experiment. Only 27% of all counted RCLs have a hyperlink to the experiment which is working (column 2). In each of the columns 3–10 we add one more criterion to evaluate the RCLs from column 2. For simplicity, these columns are ordered by decreasing number of RCLs which fulfil each criterion.

In the last column (number 11) there remains only 18 RCLs (5%) which come up with no barrier as defined above. In other words, sufficient didactical material is provided, no registration is needed, no additional software must be installed, no booking is required, they are open for any user, hyperlinks are working, etc.

Readers who are interested in these findings may have a closer look at the collection of websites of RCLs. Even if these research findings are from around 2010–2011, one easily can find working groups active in the field of RCLs and then one may follow recent developments (for example, see best practice examples [3–6]). A search in related journals can prove to be very time consuming. On the other hand, a search engine like Google scholar may be applicable, but with less effort. To the best of our knowledge, no other collection of RCLs worldwide comparable to the herewith presented one has come to our attention. However, a collection of literature on RCLs, although not up-to-date, should be mentioned in this context to complement our statements [7].

To conclude briefly: a large number of RCLs are already available (∼100 for physics teaching). According to our evaluation procedure only a few fulfil a minimum of certain standards and seems to be suitable for teaching. In the landscape of teaching aids, RCLs are recognized as a new medium which is meaningful and expands the possibilities for a teacher in practice. Even if new techniques arise from the computer industry, the principle of this medium will survive at least in the near future.

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