Abstract
Laboratory-based courses play a critical role in science education, yet there is disagreement between science and engineering educators about whether and which types of technology-mediated laboratories should be involved to promote better conceptual understanding, better design skills and better professional skills of learners. In this study, we focused on the evaluation of the efficiency of different types of e-labs, using Ma and Nickerson (2006) four-dimensional educational goal models. We found different patterns and enlarged the model to five dimensions. We tried to specify clearly the differences, advantages and disadvantages of all three kinds of e-labs according to educational goals to be achieved. We also tried to investigate which aspects of the laboratory experience are most essential to learners and if those lab characteristics have a relationship to learner characteristics or to prior experience. In the second part of the study, we focused on investigating (not verifying) the hypothesis, that it is not the actual nature of the laboratories, but the beliefs that students and teachers have about them which may determine the effectiveness of different lab types.

Keywords
science education, remote laboratories, virtual laboratories, conceptual understanding, educational research

INTRODUCTION
Contemporary problems in science education are closely connected to a paradigm shift in teaching and learning, necessitated in the few last years by the impact of the globalised world, together with the information revolution and on-going needs of the knowledge society. Some general features can be recognised in this movement (Derrick, 2002). Among them, the following elements seem to be the most important for science education:

1. A focus on uncertain (not exactly defined) situations
2. A focus on conceptual understanding
3. Usage of a holistic, as opposed to a discrete, approach
4. Teamwork and virtual teams scattered around the world
5. A blurring of the difference between mental and physical work

There is no doubt that all above-mentioned items are closely connected to actual experimentation and laboratory work.
According to a still-valid document of the American Association of Physics Teachers (AAPT, 1997), it is in the laboratory, where students are supposed to obtain "significant experiences with experimental processes, including some experience designing investigation." It is again in the laboratory, where students gain their hands-on experience and thus blur the difference between mental and physical work. It is also in the laboratory, where students "master their basic science concepts" and it is laboratory work which "helps students understand the role of direct observation in science and to distinguish between inferences based on theory and the outcomes of experiments" (AAPT, 1997). Thus, the laboratory landscape, especially computer-mediated, networked laboratory landscape, seems to represent the best training platform for the teaching and learning paradigm shift, necessary for today's knowledge society.

Nowadays laboratories, generally called “e-labs” (“simulated labs” or “virtual labs”; “remote labs”; “computer-mediated, hands-on labs”) offer a large variety of new techniques, new learning environments and new tools: from project and modelling tools, interactive screen experiments, to remotely-controlled devices. It is plausible to adopt the statement that these kinds of e-labs will be the typical learning environment for science students in the future. But do they really promote better conceptual understanding, better social skills, including teamwork and networking and better professional skills?

Educational laboratory research surveys (Hofstein and Lunetta 1982, Hofstein and Lunetta repeated study, 2004, Ma and Nickerson 2006) often conclude with a call for more empirical research using agreed outcome measures and larger sample sizes. There are many reasons why there have been relatively few educational evaluations of laboratories. Firstly, the newer technologies are built by engineers and scientists who usually write about technical design matters, rather than educational evaluation issues. Secondly, even if there is a desire to evaluate the new technologies, comparing the new labs against alternative strategies is not always easy, given their different qualities. Thirdly, the laboratory equipment may be inherently specialised, which means that few students will be prepared to use it in any given semester. Thus, the studies, that are done, usually have small sample sizes.

Since there is a lack of criteria for the evaluation of the pedagogical effectiveness of the three types of e-labs, we used the results of the comparative literature study (Ma and Nickerson, 2006), including more than 60 very instructive research studies. Ma and Nickerson discussed mainly the following: (1) design skills, (2) conceptual understanding (3) social skills (including teamwork and networking) and (4) professional skills. On the basis of interviews with experts and teachers (Lustigova and Lustig, 2008, 2009), we decided to enlarge the set of criteria and replace “professional skills” by (a) inquiry planning and (b) data-processing. Together with (c) design skills, (a) and (b) were understood as professional skills.

In their comparative study (2006), Ma and Nickerson also examined the possibility that it is not the actual nature of the laboratories, but the beliefs that students have about them, which may determine the effectiveness of different lab types. More than 50 years ago, Miller (1954) clearly discerned two different kinds of “fidelity”: engineering and psychological. He found that engineering fidelity concentrates on the closeness of simulated environments to physical surroundings, while psychological fidelity is seen as the determining factor for the effectiveness of a simulation device. More recently, Patrick (1992) and Lustigova (1996) reported that simulation with high psychological fidelity can lead to a high transfer of learning, despite low physical fidelity.
RESEARCH METHOD
The first part of our study was exploratory in its nature and focused mainly on verifying (and modifying) the four-dimensional goal model for laboratory education, developed by Ma and Nickerson in 2006. To gather information from the respondents (both students and teachers) we used questionnaires, interviews and observations. Initial questionnaires collected mainly demographic data, other facts and preferences.

Observations (both online and in situ) were used to reveal some of the professional skills and social skills, including teamwork and networking. Interviews with teachers helped us to reveal students’ design skills. We also examined the worksheets of 29 students. These worksheets were especially developed to reveal conceptual understanding and data-processing skills within different laboratory tasks.

Learners’ and teachers’ beliefs in the importance of different aspects promoting conceptual understanding were investigated during the second part of the study. To gather data in the second part of the study, we used only interviews and questionnaires. This part of the study also revealed which aspects of the laboratory experience were most essential to learners and if those laboratory characteristics had a relationship to learner characteristics or to prior experience.

While surveying, we included eight questions focused on the demographic and educational experience of the student participants and the demographics, work and teaching experience of the participant teachers. Additionally, ten questions rated on a 1 to 9 scale (with 1 being the lowest and 9 the highest) were focused on the beliefs of both learners and teachers. These questions were adapted from Corter, Nickerson et al. (2007) study and enriched by a few others, selected on the basis of interviews with experts.

The whole survey (part 1 and part 2) was exploratory in nature and has not been validated or aligned with other instruments evaluating satisfaction with laboratory characteristics. It will serve as a potential baseline for investigation in this area. All obtained data were processed with the help of MS Excel. In order to investigate differences in student ratings, we ran a k-means cluster analysis (SPSS statistical software). The relatively low number of participants did not allow for full verification but offered some new hypotheses to be verified.

FINDINGS AND DISCUSSION
Pedagogical effectiveness of e-labs in five-dimensional model
In the first part of our study based on both qualitative and quantitative research methods, we focused on aspects defined by AAPT (1997) and developed by Ma and Nickerson’s in 2006. We discussed mainly professional skills, including: (1) inquiry-planning, (2) design skills, (3) data-processing, (4) conceptual understanding and (5) social skills (including teamwork and networking). A comparison of the Ma and Nickerson results (2006) within their four-dimensional model and our five-dimensional model results (2010) are presented by the following graphs.
Figure 1: The educational goals of current laboratories: (a) remote (solid line); (b) virtual (dotted line); (c) computer-based, hands-on (dashed line) (Ma and Nickerson, 2006)

Figure 2: The educational goals of current laboratories: (a) remote (solid line); (b) virtual (dotted line); (c) computer-based, hands-on (dashed line) (Lustigova, 2010)

**Remote laboratories**

We found that students in remote laboratories greatly improved their data-processing skills. Working on their own computers and undisrupted by co-workers and the unknown laboratory territory, they focused on the problem and reached significantly better results.

Thanks to fast graphical visualisation and to the great potential of remote labs to re-collect data and re-run experiments under many different settings, they also improved their conceptual understanding.

**Hands-on, computer mediated laboratories**

The work in computer-mediated, hands-on laboratories mainly helped students to improve their design skills and also teamwork and social skills. They really appreciated the help of co-workers during the setting-up of the experiment and also in data-processing activities. By comparison with the experience in remote laboratories, students in hands-on laboratories did not improve their data-processing skills as much as we expected.
Virtual laboratories

Virtual (or simulated) laboratories are often used by many teachers as an alternative to traditional, hands-on laboratories. The reasons are mainly economical and spatial. Further, the comfort, they offer to both, students and teachers, plays an important role. Our research results confirmed our beliefs that, in the way they are offered to students, virtual labs do not have a strong impact on students' learning outcomes.

Undergraduate students over-estimated or under-estimated the validity and reliability of the data, they obtained. Experienced students were very critical of experiment plans seen on virtual labs and were often confused by the results they obtained. Since the experimental settings' ranges are usually very limited, repeating data collection under a different set-up did not help.

Students' and teachers' beliefs

In the second part of our study we focused on specific aspects of laboratory work, identified by Corter, Nickerson, Esche et al. (2007), which students believed to be most useful in promoting their conceptual understanding. Students in their study rated physical presence in the lab as the most important. Teamwork was rated as the second most important aspect, suggesting that they are well aware of the educational value of collaborative work effort. Data acquisition was rated the third most important, followed by preparatory instructions, and the laboratory report

Since we were aware of a big difference between the beliefs of new undergraduates and nearly-qualified future teachers, we exposed two different groups of students - first year students and final year students to the same set of questions.

The results, compared to the results of Corter, Nickerson, Esche et al study (2007) are in the following table:

<table>
<thead>
<tr>
<th></th>
<th>Corter, et al study</th>
<th>Ch. U. freshmen</th>
<th>Ch. U. last year students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical presence in the lab</td>
<td>7,03</td>
<td>7,1</td>
<td>5,1</td>
</tr>
<tr>
<td>Collaborative teamwork</td>
<td>6,78</td>
<td>5,6</td>
<td>7,1</td>
</tr>
<tr>
<td>Data acquisition</td>
<td>6,57</td>
<td>7,1</td>
<td>6,5</td>
</tr>
<tr>
<td>Preparatory instructions</td>
<td>6,26</td>
<td>7,1</td>
<td>5,4</td>
</tr>
<tr>
<td>Preparation of the lab report</td>
<td>5,71</td>
<td>5,1</td>
<td>4,1</td>
</tr>
<tr>
<td>Immediate feedback</td>
<td>Not rated</td>
<td>7,18</td>
<td>6,4</td>
</tr>
</tbody>
</table>

Table 1: Students’ ratings

The results obtained lead us to the hypotheses that experienced students (with higher level of professional skills), prefer those aspects, which are not closely connected with the physical presence, while freshmen appreciate physical presence and also the presence of team-mates and teachers.

The "immediate feedback" aspect, which is missing in Corter, Nickerson et al. (2007) study, was highly rated by both, first and final year students. Thus, it may be suggested that this aspect plays an important role in promoting conceptual understanding, regardless of whether the feedback comes from a teacher, or from a machine.
Since we found no research surveys focused on teacher’s beliefs about students’ conceptual understanding in relation to the promotion of the three types of e-labs (remote labs, virtual labs and computer-mediated, hands-on labs), we had to develop new set of research questions based on earlier research and observation.

<table>
<thead>
<tr>
<th></th>
<th>University teachers</th>
<th>Secondary school teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data analyses</td>
<td>9,1</td>
<td>4,3</td>
</tr>
<tr>
<td>Physical presence in the lab</td>
<td>8,9</td>
<td>9,8</td>
</tr>
<tr>
<td>Data acquisition</td>
<td>8,1</td>
<td>6,2</td>
</tr>
<tr>
<td>Preparatory instructions</td>
<td>7,6</td>
<td>9,6</td>
</tr>
<tr>
<td>Preparation of the lab report</td>
<td>7,5</td>
<td>5,2</td>
</tr>
<tr>
<td>Collaborative teamwork (incl.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>teammates feedback)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teachers feedback</td>
<td>7</td>
<td>8,6</td>
</tr>
<tr>
<td>Possibility to change parameters easily and repeat measurement</td>
<td>7</td>
<td>3,2</td>
</tr>
<tr>
<td>Data graphical visualization</td>
<td>6,7</td>
<td>9,1</td>
</tr>
</tbody>
</table>

Table 2: Teachers’ ratings

As expected, secondary school teachers preferred and highly-rated mainly those aspects, which are closely connected with traditional “recipe-based”, hands-on labs (physical presence, preparatory instructions and teachers feedback). The only highly-rated aspect, which is more closely connected with the use of ICT technologies, was graphical visualisation.

Further, university teachers (who are still more or less used to teaching and working in traditional or computer-mediated, hands-on labs) overestimated aspects, connected with physical presence of both teachers and students. But they also emphasised the possibility of changing parameters easily and repeating or re-running measurement under different conditions. As the university students, they also, rated highly data analysis, data acquisition and collaborative teamwork.
Both groups agreed on the importance of feedback.

CONCLUSIONS AND RECOMMENDATIONS
Both above-mentioned surveys answered some of our research questions but also brought up new ones.

It seems that remote and partially also virtual laboratories do well in promoting conceptual understanding, but why? Based on responses to the survey and interview questions, one of our hypotheses is that students performing remote and simulation-based labs have more opportunity to repeat experiments, vary parameters and observe their effects, and otherwise structure their own learning.

We also found, that students’ learning-related behaviour (including laboratory group interactions) differs for remote and simulated laboratories, as compared to hands-on labs. As a result of the interactive control they exert over the data-acquisition apparatus in remote and simulation-based laboratories, individual students construct better inquiry-plans and retain knowledge longer.
Conversely, our findings in co-ordination and communication patterns show that laboratory team-mates in remote and simulation conditions communicated with each other even more often than students in traditional hands-on environments. They discussed not only the experiment results, but also the experimental design and data-acquisition process. Less technology-skilled students seemed to be under the permanent control of those with greater skills.

Since we expected different results, namely that (1) new technologies might lead to more individualistic interactions with apparatus in the data-acquisition phase and (2) some students may take a passive role in organising activities and collecting data, we would like to continue to maintain surveillance of our target group and to increase the diversity of laboratory tasks and observe and report on what happens.

REFERENCES


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Biographies

Zdena Lustigova is the head of the Laboratory of Distance Education, Faculty of Mathematics and Physics, Charles University in Prague, Czech republic. Her educational work and especially her research and development effort has been concentrated on neurophysiologic aspects of e-learning and computer aided teaching and learning.

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