On physical experiments and individual assessment of laboratory work in engineering education

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ABSTRACT
It is obvious that our society needs more engineers. It is also true that mankind must live in symbiosis with nature and focus on sustainability and understanding. Thus, engineers must be able to design products and services which are in line with the principles of nature and the only way to become familiar with these principles is to perform many physical experiments. A way to use instructional laboratories more effectively and offer more hours in the laboratories for students without significant increased cost per student is opening them for remote access. Hands-on experiments are indispensable but remote mouse-cursor-on ones can supplement them. The VISIR (Virtual Instrument Systems in Reality) Open Laboratory Platform offers an open standard for online workbenches enabling students not only to perform physical experiments 24/7 but also to practice laboratory work. Learning objectives of laboratory work, free access to laboratory resources, and individual assessment of such work should be important key elements in an education delivering engineers with a solid documented laboratory experience.

Keywords
Laboratories, learning objectives, assessment, remote laboratories.

1. INTRODUCTION
It is obvious that our society needs more engineers. It is also true that mankind must live in symbiosis with nature and focus on sustainability and understanding. Not only the number of students opting for engineering must increase but universities must deliver engineers who are able to design products and services which are in line with the principles of nature. The only way to learn, so far unknown principles, is to perform physical experiments. However, during the last decades universities in Sweden and in several other countries have decreased the number of laboratory classes in engineering education bit by bit. The prime cause is clearly due to the task of handling the dramatically increased number of students, whilst staff and funding resources have not improved [1]. A second cause is the digital evolution. Simulators which are based on mathematical models have evolved and simulations have to a large extent – sometimes without due consideration - replaced experiments in engineering education. However, certain experiments should be replaced by simulations. Hand calculations and simulations are the best tools to learn theories and mathematical models because no noise or other imperfections not included the model will hide the expected result. On the other hand, physical experiments are indispensable because they offer the only possibility to see the relevance of models and the differences between results of calculations based on models and results based on observations of nature [2], [3]. Thus, physical experiments can do more than simulations.

This paper discusses tools and methods for increasing students' access to laboratory resources as well as learning objectives and individual assessment of laboratory components. These three key elements should enable universities to deliver engineers with a documented solid laboratory experience. Such documentation is particularly useful for employers who need to hire experimenters.

2. SOME HISTORY
For centuries, scientists have performed physical experiments in order to create mathematical models and theories describing phenomena of nature. Professional engineers have these models and theories in their mind and use simulators to design prototypes. However, they perform experiments too but for two other reasons [4]. First, in the design process they often "ask" nature when they suspect that certain aspects of the models to be used may not be accurate enough. The second reason is to determine if a prototype meets the specification and performs as intended in the environment where the product is to be used. Students perform experiments to learn laboratory workmanship and to see that existing models are useful descriptions of nature even if they are not perfect. Seeing the exuberance of phenomena of nature is an instructive and inspiring experience arresting anybody's attention.

Let us look back a few decades to the sixties when engineering education was very popular and attracted the best students. Engineering was a high status profession in many countries and the universities of technology were well funded. The laboratories were well equipped and the laboratory components of the courses were numerous. For example, the Royal Institute of Technology (KTH) in Stockholm, Sweden, had a thermal power station of its own producing heat for the university and it was also used in courses allowing students to perform experiments in industrial

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scale. In the mid sixties the first author (Ingvar Gustavsson) was an undergraduate student in electrical engineering at KTH. He took courses in measurement and instrumentation technologies where the dominating part was supervised laboratory classes. The learning objectives were unspoken or tacit but each laboratory class covered a certain aspect of the subject. The courses ended with both written and practical exams. The practical exams took place in the laboratory where there were eight workbenches without equipment. When the student at one of the workbenches had considered the assignment she had to list equipment needed and its performance. Then a laboratory instructor brought it from the storeroom. If you, for example, ordered just an oscilloscope then the instructor most certainly would bring one from the department museum. Finally the student discussed her results with the professor who was also present. This examination form engaging a professor and an instructor for only eight students was expensive. It was abandoned later during the sixties because of reduced course funding. Then KTH lost its capability to deliver masters of electrical engineering with a documented laboratory experience.

3. LEARNING OBJECTIVES OF LABORATORY WORK

While there seems to be general agreement that laboratory classes are necessary in engineering education, little has been said about what they are expected to accomplish. *If you don't know where to go, you won't know which road to take and you won't know if you have arrived*. This truism, when applied to education suggests that clear learning objectives and assessment are essential in designing an effective learning system. The lack of articulated learning objectives of laboratory work became clear to ABET (Accreditation Board for Engineering and Technology) in the US when distant education programs began inquiring about accreditation. As a result of ABET activities thirteen learning objectives was defined [4], [5]. The first five objectives are dealing with cognition – Instrumentation, Models, Data Analysis, and Design. The psychomotor domain i.e. the ability to actually manipulate apparatus is also represented. The remaining objectives have a cognitive part but also include a significant component of the affective domain – learn from failure, creativity, safety, communication, teamwork, and ethics in the laboratory. Using these objectives as a framework, laboratory developers and educational researchers can identify the specific objectives that their work is expected to achieve. Examples of less detailed learning objectives of laboratory activities presented in other papers are [6], [7], [8]:

1. To illustrate and reinforce concepts and theories.
2. To develop skills in use of instrumentation and other equipment.
3. To develop an understanding of the non-idealities in the real environment.
4. To develop social and teamwork skills in a technical environment.

To achieve the first objective and to some extent the second one qualified simulators could be used but the second and especially the third objectives require much work in a laboratory.

4. FREE ACCESS TO LABORATORIES IS DESIRED AND SHOULD BE POSSIBLE

At many universities the students are permitted to be in the laboratories only during supervised laboratory classes when an instructor is present. Supervision means tutoring but also looking after that no student will be harmed and that the expensive equipment will be handled properly and will not be damaged or stolen. Time in a laboratory is expensive counted per student, directly in the cost of the instructor and the technicians required maintaining the laboratory, but also indirectly in costs such as the cost of hardware and the provision of laboratory space. In instructional laboratories at most universities there is a number of laboratory workbenches where at maximum the same number of students or mostly pair of students perform experiments. The number of workbenches in a hands-on laboratory is usually selected considering how many students an instructor can supervise if a workbench is not too expensive. Typically, instructional laboratories for electrical experiments are equipped with eight identical workbenches. Fewer workbenches mean more teaching hours per course but less investment. It is a pedagogical advantage if the workbenches are identical because then the students can perform the same experiments in each class and in the correct order required by the course. On the other hand it implies larger investments i.e. more copies of every instrument.

To cope with the requirements of a sustainable society and meeting the students' desire to organize their studies freely the students should be granted free access to experimental resources. Would it be possible to accomplish this within the current course funding using remote control of laboratory equipment as a supplement? The Signal Processing Department (ASB) at Blekinge Institute of Technology (BTH) in Sweden started a feasibility study in 1999. The vision was creating an online replica of a traditional laboratory workbench for electrical experiments in order to provide free access to the laboratories for the students albeit hands-on would be replaced by mouse-cursor-on. Computer-based instruments will sooner or later replace the desk top ones used in the laboratories today because such instruments have smaller footprint and buttons on a screen are cheaper than physical knobs. Then there should be little difference for the students located proximally or remotely if they control the instruments with technology-mediated interfaces.

In general laboratory workbenches for electrical experiments comprise power supplies, a function generator, an oscilloscope, a multi-meter, and a solderless breadboard. Figure 1 shows such a workbench in a hands-on laboratory at BTH. The small components (an operational amplifier and 8 resistors) in the lower left corner of Figure 1 at the arrow are the set of components provided by the instructor to be used in a certain laboratory session. Most instruments in an electronics laboratory have a remote control option but the breadboard has not. To open a workbench for remote access a circuit wiring manipulator possible to control remotely is required. A switching matrix equipped with electro-mechanical relays can serve as such a device [9], [10].

Now, approximately 20 person-years after the start of the feasibility study online workbenches for electrical experiments based on the VISIR Open Laboratory Platform are in operation at BTH and at three other universities in Europe. VISIR is a project about disseminating the platform [11]. A software distribution is released under a GNU GPL license [12]. The aim of the VISIR project is establishing a VISIR Community of collaborating universities/organizations further developing the laboratory platform and sharing laboratory resources and course material in order to improve engineering education. The International Association of Online Engineering (IAOE) has organized a Special Interest Group for VISIR (SIG VISIR) for people who are interested in Online Engineering especially in opening university laboratories for remote access 24/7 [13]. The goal of the VISIR Community is tools and methods enabling universities to offer ubiquitous access to laboratory workbenches without raising the running costs per student. A side effect could be much more people interested in engineering education if access is offered for the public when the equipment is not used in regular education.

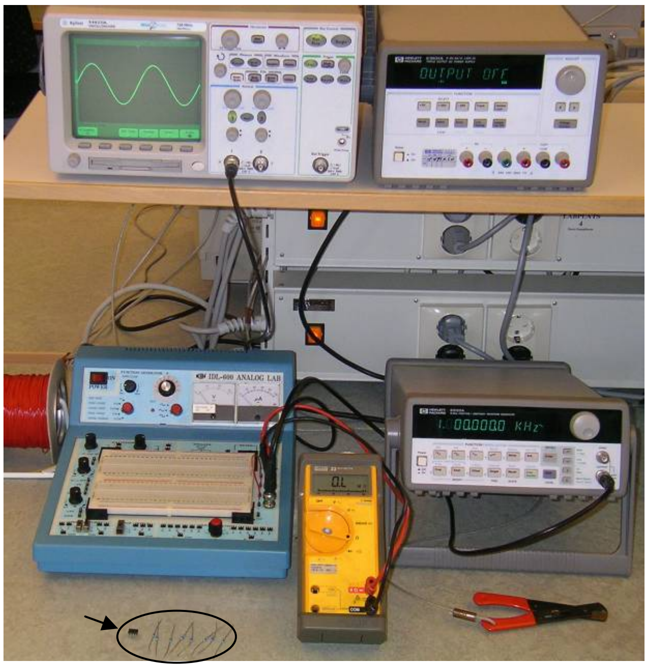

Figure 1. Workbench in a local laboratory for electrical experiments at BTH.

The online workbench has been presented earlier [14], [15]. Virtual front panels depicting the front panels of the desktop instruments are used to control the instruments and the wiring on a virtual breadboard controls the switching matrix. The set of components provided for a certain laboratory class is installed in the matrix and will be displayed in a component box at the top of the virtual breadboard. In Figure 2, most of the components have already been moved to the breadboard and a circuit has been wired. The circuit that an experimenter wires on the breadboard, using the mouse, is checked by a virtual instructor, which is a software module. The teachers create rules for the virtual instructor. If an instrument or some component in the switching matrix happens to be damaged a teacher is to blame not the student who caused the damage.

By selecting appropriate values of the components controlling the time constants, it is possible to study a certain phenomenon at different time scales. This feature is used in the online workbench to allow simultaneous access by time-sharing. The teachers who design the experiments to be performed in a laboratory session are instructed to select the values of the components so that an experiment last less than 0.1 s. Time-sharing is used to allow many students to perform experiments simultaneously. In this way, one workbench can emulate a whole laboratory with many workbenches. However, the student can use all the time she needs to wire her circuit and set up the instruments. Her circuit and the instrument setup are sent to the server only when she presses the *Perform Experiment* button. Then the client software sends a message containing a description of the desired circuit and the instrument settings to the workbench (server). If the workbench is not occupied, the desired circuit is created in the matrix and the experiment procedure is performed. Then the result or an error message is returned to the requesting client computer. Otherwise, the request is queued and the execution is somewhat delayed.

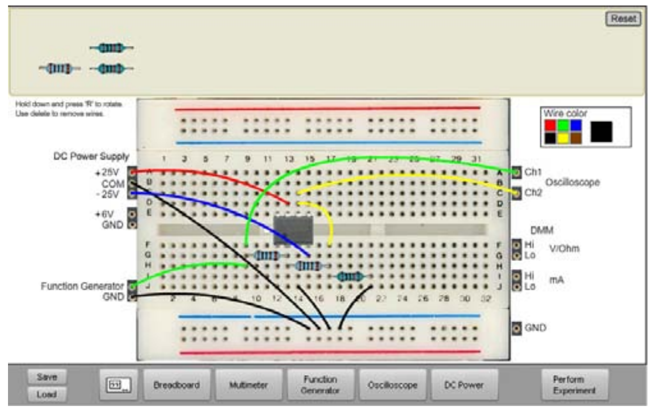

Figure 2. An op. amp. circuit wired on the virtual breadboard.

The online workbench at BTH is used in three ways:

1. In supervised laboratory classes in the hands-on laboratory where students can select if they want to perform the experiments hands-on or mouse-cursor-on. However, in the first laboratory class hands-on is compulsory.
2. In supervised laboratory classes in distance learning courses, where the students are scattered all over the country. Remote desktop software and MS Messenger is being used to communicate between the students themselves and between the students and the instructor. More advanced means of communication will be adopted.
3. Students can prepare supervised laboratory classes and perform the experiments at home, knowing that the equipment in the hands-on laboratory looks and behaves the same. They can repeat experiments afterwards as well. Inexperienced or students requiring more time, appreciate these possibilities. A student wanting, for example, to master the oscilloscope, can practice in the privacy of his/her own home without anybody watching.

The next way to use it will be low-cost practical exams of laboratory work.

5. INDIVIDUAL ASSESSMENT OF LABORATORY WORK

In circuit analysis courses at BTH the students must analyze every circuit in the laboratory instruction manuals using both hand calculation and simulation before supervised laboratory classes. If the results emanating from the two methods are identical the students have reasons to believe that their calculations are correct. The final step is performing the corresponding experiment in class using the online workbench or a proximal one. If the result still is the same students have reason to believe that the theory works in real life. Unfortunately, some students do not spend so much effort on the practical part. They concentrate on the written exam and rely on a colleague who knows how to perform the compulsory practical part. In the last laboratory class of the circuit analysis course the students are supposed to identify a circuit comprising three passive components in a "black box". It would be interesting to move the written exam to a room where the examinees could access the online workbench and substitute one of the theoretical problems for a practical one, for example, identifying the circuit in the black box with other components than during the laboratory class. Would such an innovation make students more interested in the practical part? The first author still remembers that the practical assessment to come encouraged him to take the laboratory classes extra seriously. If students are granted free access without health and safety risks and individual assessment is introduced they may do more on their own and learn more from nature.

6. CONCLUSIONS

A sustainable society needs engineers who are familiar with experimenting and laboratory work in general. Three key issues should be (1) learning objectives of experimenting and laboratory work, (2) individual assessment and (3) free access to laboratories for students. Objectives have been presented and are being discussed. They should be assessed individually in the same way as the theoretical ones are. Online workbenches can supplement hands-on ones enabling universities to increase the capacity of their laboratories and to offer free access 24/7 to physical equipment without a substantial increase in cost per student. Even though much remains to be done concerning these new tools they are ready for exploration by pedagogical experts and engineering educators globally in an interdisciplinary research combining the tools with learning objectives and individual assessment of laboratory work. Free access not only offers more opportunities and time for experimenting in the laboratories but meets the students' desire to organize their studies freely. This desire is very much in line with the Bologna process. This is also true of the ideas presented here. The universities are required to declare *developed skills* of graduated engineers and *aim and learning outcome* for each course.

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