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The LABORATORY©-concept is designed to allow students to perform real experiments at any given time in a similar way students consult books in a library. For this lab-instructions and material are configured to give both free access and autonomous use, while students are released from tedious and distracting tasks. The concept is demonstrated through case studies in Electromagnetics in which all three pillars of autonomous labs have been successfully applied. 1) Intuitive user-lab interface, 2) interactive guidance, 3) Emphasized focus on main topic. Success results are shown by student questionnaire.

PHILOSOPHY OF THE LABORATORY© CONCEPT

The laboratory exercise is an indispensable part of the education curriculum of applied sciences. At the same time organising lab exercises classically constitute a considerable cost for the faculty due to very costly equipment and infrastructure, as well as the cost of highly qualified personnel. Classically these costs increase roughly linearly with the number of students to be served. This places strong demands on an efficient organisation of lab exercises in order to reduce costs, which unfortunately often inflicts a corresponding reduction in didactic quality.

In the LABORATORY© concept, optimisation of the laboratory infrastructure and didactic quality are not in conflict. However, the essence of this concept is that it allows the students to autonomously perform an experiment out of a library of experiments at any given time.

One of the basic ideas in this concept is that the lab exercises are configured in such a way that the students can carry out the exercise autonomously, as individuals, or in small groups of 2 or 3 students. Achieving this renders a series of possibilities concerning improving the didactic level of the lab exercises as well as the practical organisation of these.

The listing below shows examples of improvements that the concept will render. It will

Didactic improvements
- allow the student to choose his/her own pace
- improve the possibilities for the student to repeat parts of the lab exercise which to him/her were less clear
- reduce overhead, i.e. connecting and configuring devices, when these activities are not the purpose of the lab exercise
- improve student involvement through enabling a choice of lab exercises, e.g. 3 out of 5
- stimulate the student to work and solve problems independently

Practical improvements
- enable assisting personnel to spend more time on guiding the students in the interpretation process rather then the execution of the lab exercise itself
- make it possible for students to choose the date and time when they carry out the lab exercise
- improve the maintainability and further development of the lab exercises

The reason why the lab exercises in the LABORATORY© concept are well suited with respect
to maintenance and further development is due to the inherent documentation. In order to enable the student to autonomously carry out the lab exercises, the instructions must be of a high quality. An instruction that is clear enough for the student, including extra optional information, is more likely to be clear enough for e.g. new lab personnel. One may argue that this could be the case for any lab exercise. However, experience shows that if documentation is not an inherent part of the development of the lab exercise (or any development) it tends to be neglected.

**Real lab exercises**

In this concept it is further central that the students should have the possibility to autonomously carry out “real” lab exercises. “Real” here refers to direct or indirect interaction with physical components, this in contrast to simulations. Real lab exercises normally involve risks for both the students and the lab equipment.

**CONDITIONS FOR SUCCESSFUL IMPLEMENTATION OF THE LABORARY© CONCEPT**

The first series of lab exercises implemented according to the LABORARY® concept indicate that in order to achieve what is listed above the following set of conditions must be fulfilled.

**Intuitive interface**

The way information is presented to the student during a lab exercise plays a significant role. An intuitive or familiar interface reduces the risk for distraction and unnecessary thresholds.

**Interactive**

Giving the student the possibility to choose his/her own pace puts extra requirements on the media that is used. Just as for information presented on paper, the student must have the possibility to start, stop, go back and revisit some of the material. This must be true regardless of the media used.

**Feedback**

Actions taken by the student during a lab exercise that does not provide any feedback tends to discourage the student. Although the student did not perform any incorrect actions he/she will ask for assistance (if available). It is hence of great importance that feedback is provided for through the lab set-up. Both valid and invalid actions should generate feedback. If this kind of feedback is not generated the student will remain uncertain about his/her performance preventing him/her to learn confidently. Furthermore, in order to get good insights of the matter in a lab exercise the feedback must be sufficiently fast. Otherwise the students tend to loosen confidence in the interactive process.

**Safety and protection**

For the safety of the student and for the protection of the equipment, a system or mechanism is required which can monitor the student action and intervene when necessary.

**EXAMPLE OF IMPLEMENTATION OF THE LABORARY© CONCEPT**

At the laboratory of the group MTT, which provides the technology lab exercises for the students of Economics Engineering at the faculty TEW, a first series of lab exercises has been implemented based on the LABORARY® concept, one for chemistry [1], and four for electromagnetism.

**Multimedia PC plus LabVIEW™**

The choice has been to use multimedia enhanced lab course material in general and multimedia equipped PCs in combination with LabVIEW™ in particular. It is important to point out that for the LABORARY® concept as such PCs are not compulsory. However, since the ratio flexibility/cost for PCs is very favorable and improving yearly, it seems the best choice.

In this project a number of lab exercises are developed which are computer controlled and where the students are both monitored and guided by the computer software. The system makes it further possible to reduce the number of tasks the student must perform to only those relevant for the understanding of the lab exercise, hence reducing overhead. The computer can do for example the tedious task of collecting and presenting data in a graph. Furthermore does the general interface, built with LabVIEW™, allow the student to perform experiments without having prior knowledge of apparatus such as oscilloscopes. This is of special value since it otherwise would both require extra lab sessions
for teaching the handling of the apparatus, and the purchase of a series of such equipment.

**Internet-like interface**

From the choice of using a multi media PC the use of an internet-like interface flowed naturally. Almost all students are familiar with Internet browsers and hence feel confident when confronted with an internet-like interface during the lab exercise. Never the less special care must be taken when developing the internet-like info pages not to overload them with information and thereby lossoing the benefit just gained.

The word internet-like is used on purpose instead of e.g. HTML since there are several other possibilities in addition to HTML (and its derivatives) to create an interface which allows the user to interact. For instance, the interface of the lab exercises on electromagnetic phenomena has been developed using the graphical development language LabVIEW™. This tool allows for the “pages” to be generated in much the same way as is commonly done with any kind of web-building tool. Below “page” is used to denote a single screen, scrollable or not, showing information and allowing for interaction.

Some of the pages generated for one of the four lab exercises on capacitors (in the series electromagnetism) are shown in figure 1 to figure 4. The student navigates through the lab exercise by clicking on the "back" or "next" buttons at the bottom of each page (in Dutch “terug” and “volgende”). This provides a clear similarity with browsing through a web-site and hence feels intuitive for the students.

**Typical parts of lab exercises**

Each lab exercise has about the same typical parts or pages.

- A login part where the students identify themselves, as individuals or by group.

- An introduction part informing the student about which lab exercise is to be carried out and which prior knowledge is expected of the student, i.e. which courses the student should have taken prior to performing the lab exercise

- A part giving information on the theory that is to be explored (fig. 1).
- A part where the students may be prompted for the answers to one or a few questions. The student can only proceed with the exercise after giving the correct answers.

- A part giving the practical instructions describing how to carry out the actual activities and measurements of the lab exercise (fig. 2).

- A part handling the interaction during the actual measurements and the displaying of the results (fig. 3).

- A part giving an overview of the results of the exercise, allowing the student to print these results and/or optionally transfer the results to the students' own computer account by e.g. email. It is based on these data that the student will prepare a lab report (fig. 4).

**Stand alone application**

The set of LabVIEW™ pages making up a lab exercise can be browsed as separate pages but may also be bundled and turned into a stand alone application using the LabVIEW™ application builder.

There are several reasons to do this: more robust execution, reduced number of files to distribute to several PCs, etc. A more important reason is however the possibility to switch off information and possibilities for interaction in the compiled version compared to the non compiled version of the lab exercise. This allows for attaching extra information to the lab exercise that is only relevant for the laboratory personnel and developers of the lab exercise.

In the compiled version this information is neatly disabled in order not to distract the student. The same is true for most kinds of interaction, which should not be enabled for the student, e.g. resizing windows and buttons, changing scales of graph axes and stopping the execution.

In addition this allows for changing the level of complexity of the lab exercise by compiling different version with different options.

**Praktische aspecten van de meet- en meetvormingsfaciliteiten**

**Algemene behoeften**

Het behoud van deze proef is er om de verhaal te bepalen tussen de capaciteit van de polster en het oppervlak van de polster. Hierbij is natuurlijk dat de gelijkmatigheid en exactte meetvormingen in een bepaald meetvormingsgebied, welke van elkaar onafhankelijk zijn te benadrukken.

**Interactieve behoeften**

Voor de monteringsbepaling benadrukt je over een verhaal. De meetvormingsverspreiding (fig. 4) van de gecontroleerde meetvormingen is niet op de meeste meetvormingen te zien. De meetvormingen worden op een volgende pagina’s (deze volgen op de meten) de bijkomende meetvormingen in function van het volume van het materiaal

**Nota bene**

Figure 2. One of the linked instruction pages from the lab exercise “capacitive volume measurement” is situating the practical handling.
Low cost LabVIEW™ implementation using PC-soundcard

In order to perform measurements using LabVIEW™, from National Instruments (NI), one requires both a PC as well as data acquisition hardware. This hardware must be compatible with LabVIEW™, i.e. drivers must be available. Since, in many cases this means that there is only one source for this hardware, namely NI, prices tend to be high and the total solution costly. However, NI provides some general-purpose drivers and drivers for hardware other then from NI, hence enabling the user to combine existing hardware with LabVIEW™.

In the four lab exercises on electromagnetism it is the PCs own soundcard which is used as data acquisition hardware. Since this is already present in a multimedia PC this choice generated zero extra cost.

A standard soundcard has typically one audio input (stereo) one audio output (stereo) and one microphone input (mono), but there are soundcards with a multiple of both inputs and outputs. However, the drivers from LabVIEW™ do not support the channels of the soundcard but rather the audio recording channel and the audio play channel of the operating system. This reduces the number of channels to maximum two single ended input channels and two single ended output channels per soundcard.

How useful a soundcard is for measurements is to some extent depending on the quality of the soundcard, e.g. amplitude and phase linearity together with bandwidth. More expensive soundcards show better values but are normally not the ones found in a standard multimedia PC. Although upgrading to a better soundcard might improve the measurements, one must remember that the bandwidth will not improve significantly and the number of channels is, due to the LabVIEW™ drivers, limited to two in and two out per soundcard. Further is the input impedance of a standard soundcard rather low, typically $10^4$ Ω. Still standard soundcards have been used for the lab exercises on electromagnetism. The way we have overcome the limitations of the standard soundcards is to measure ratios rather then absolute values and use signal conditioning electronics together with external impedance's or voltage references. Although this introduced some extra electronics the total cost is still only a fraction of that of a dedicated data acquisition device.
We have found that in spite of being limited to signal frequencies in the range of 0.1 to 10 kHz and only two input and two output channels, this provides sufficient data acquisition for numbers of the different lab exercises in electronics and electromagnetism.

**FEEDBACK FROM FIRST SERIES OF IMPLEMENTATION**

In order to test how the students reacted to the new lab exercise and to what extent we were incorporating the aims of the LABORARY© concept we carried out a survey among the students after completion of the series of lab exercises on capacitance. In this survey the students assigned a score ranging from 0 to 10 to several statements. Here 0 indicates “I totally disagree”, 5 indicates “I have no opinion” and 10 indicates “I totally agree”. The result from the survey on the main statements is presented in Fig. 5 to 10.

**Statement 1:** The information supplied by PC is ample to perform the practical aspects of the experimental set-up.

**Statement 2:** I find it necessary that the lab supervisor assists me with the practical aspects of the lab exercise.

**Statement 3:** I am able to perform these lab exercises in the lab with very limited assistance from the lab supervisor.

Fig. 5 shows clearly that information provided by means of the PC is deemed sufficient by the students.

With statement 2 and 3 (fig. 6 and 7) we wanted to test the confidence that the students have in performing the lab exercise autonomously. At the first glance these results might seem to contradict each other. Many students on the one hand require the assistance of the supervisor, and on the other hand feel confident enough to perform the exercise with very limited support. One possible interpretation of these results is that, if the assistant is present, the student will tend to ask for his support. However, if the students are placed in a situation where there is no help available, they are fairly confident in carrying out the lab exercise autonomously. Hence, the instructions are probably sufficient but asking for assistance is a matter of habit that is not so easy to let go of.
Since the LABORARY© concept also aims at the possibility to perform lab exercise remote the students were asked whether they would consider this or not (statement 4 fig. 8). The result shows that the majority of the students are not interested in doing the experiments at home. From discussions with students it was found that the large discrepancy was partially due to the lack of social interaction with fellow students if the lab experiments were to be performed at home.

**Statement 4:** If the necessary facilities were offered to me, I would consider performing these lab exercises at home.

![Figure 8. Response from statement 4 of questionnaire.](image)

Finally the students were asked if they thought they gained new knowledge from the series of lab exercises (statement 6 fig. 9). Since the most important aim of the LABORARY© concept is to reach a high didactic level this positive result is very encouraging.

**Statement 6:** From this series of lab exercises I have enlarged my knowledge and understanding of the capacitor.

![Figure 10. Response from statement 6 of questionnaire.](image)

**FUTURE GOALS OF THE LABORARY© CONCEPT**

The ever increasing possibilities of performing useful activities remotely, in particularly via Internet, suggest that also lab exercises as well could be one of these activities. However, from our survey we conclude that the lack of social interaction discourages students performing their lab exercises from home. A query among students following individual education as distance education might give a different result. Especially since this type of education almost always lack lab exercises.
Two other important reasons for wanting to perform lab exercises remotely are cost and safety. The possibilities for two institutions to share in the use, and hence the cost, of sophisticated equipment is strongly limited by geographical distance. Remotely executed lab exercises could be an opportunity to share time and hence the cost of such equipment. Ultimately, using appropriate time scheduling, the same set-up can then be used by students from different institutions. If several institutions develop complementary lab exercises based on the same principle, they may end up with an offering of a multiple of the experimental set-ups they have in their own laboratories.

Lab exercises that requires toxic or radioactive substances or any other lab exercise with increased hazards as high voltage and high power machinery could also preferably be done remotely.

That remotely executed lab exercises would be possible if required is clear from examples as remotely performed surgery.

CONCLUSION

This paper has described the philosophy of the LABORARY© concept and has demonstrated the first series of implementations.

The combination of LabVIEW™ and multimedia PCs results not only in a cost-efficient and easy to use measurement systems. It also provides a pedagogical sound electronic assistant, provides the possibility to reduce overhead and puts emphasize on the main topic.

From the results of the survey its clear that computer assisted lab exercises can work efficiently if a sound experimental set-up is chosen. Furthermore it is shown that the computer interface provides enough information and is easy to use. However there is still a demand for support for the theoretical aspects of the lab.

REFERENCES