Enhancing old laboratory experiment using flipped learning

Towards self-regulating collaborative groups in blended learning environment

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Conference Key Areas: Sustainability and Engineering Education, Continuing Engineering Education and Lifelong Learning, Students Cooperation

Keywords: Blended Learning, Cost Reduction, Flipped Learning, Laboratory

INTRODUCTION

Laboratory experiments have always been an important part of engineering education, whether they are used to relate theory and practice, or to increase motivation to learn more. [1] Laboratory can be physical, virtual, or a combination of both. For example, virtual laboratory can be a web page, in which certain laboratory experiments can virtually be executed. Simulators, which replicate reality or generate salient information about a physical process, can also be viewed as virtual laboratories. Furthermore, virtual and physical laboratories can be blended in many pedagogically instructive ways in order to exploit benefits from both perspectives. Web-based laboratory, on the other hand, is a remotely controlled physical laboratory, which allow students to access physical devices from anyplace at any time. Real-time audiovisual information from physical environment is usually delivered through the user interface of a web-based laboratory [2]. Web-based laboratories offer temporal and spatial flexibility to students with low implementation costs.

Traditional physical laboratories allow students to enter into laboratory rooms in which real processes and equipment are under operation. Such laboratory experiments link theoretical studies and hands-on experiments in concrete way. The experiments improve students' practical engineering skills, and they may also familiarize students with device malfunctions and troubleshooting. [3] Generally, physical laboratories are efficient on-site tools for familiarizing students with the "feel of engineering".

Physical laboratories and equipment may be relatively aged; for example, equipment which are more than 30 years old exists in universities. However, their educational purpose may still be very valid with relevant subject matter. In contrast, the delivery of the subject itself may be outdated, and hence, students may not reach the desired educational objectives of a laboratory experiment. At worst, an outdated approach may negatively affect to students' motivation and attitudes towards learning, which translate to undesirable learning outcome. However, technology and improved pedagogical perspective can be used to update old laboratory experiments to better suit the learning habits of the present-day students, and possibly, to positively affect their attitudes towards learning.

Currently, blended and flipped learnings are one of the most well-recognised pedagogical concepts in higher education. Blended learning attempts to integrate traditional face-to-face learning with technology-mediated practices such as online learning experiences [4-5]. Research recommends three principles for applying blended learning; namely, improved learning effectiveness, increased access and convenience, and greater cost effectiveness [5]. Flipped learning, on the other hand, promotes the importance of preliminary work and preparation in order to create successful learning episodes. Usually, internet-based, quick-access-like, technological resources are used to motivate students for meaningful preparation. Flipped learning also highlights active student cooperation as well as social interaction between the students and teachers such that creative learning environments can be established. Generally, blending strategies redefine in-class and out of class activities as well as the roles of teachers and students compared with traditional classroom.

In this paper, the author demonstrates how flipped learning, technology-driven utilities and reorganisation of the roles of students and teacher can be used to enhance an old laboratory experiment to support learner-centred model of education. To reach such objectives, technology mediated prelab activities are created to enable students to actively discover physical phenomena, which develop intuition in a timely-fashion manner. Furthermore, a thoughtfully arranged team work for increasing social interaction and collaboration between students is developed. Finally, the author show that the new laboratory work can be executed using reduced implementation costs; especially, in a mass-course.

The outline of this paper is as follows. In Section 1, the author describes a certain laboratory experiment, which has been used in a mass-course on automatic control consisting 250–300 students. During the last several years, the implementation of the laboratory work has been relatively unsuccessful and outdated, which has translated to undesirable learning experience for large group of students. In order to compensate such shortcoming, the author has refurbished the implementation of the laboratory experiment using blending strategies, which are discussed in Section 2.

To be more specific, the author has supplemented written material with a teaser video in order to digitally deliver interesting content to students. The purpose of the video is to allow a remote visit to the laboratory before students physically enter there. The video gives a quick overview of the laboratory equipment and their interconnections through carefully coordinated callouts. In addition, new simulation software has been created, which instantaneously produce similar results as the actual experiment does. The software can therefore be viewed as a virtual laboratory, and it is used to improve students' preparation for the experiment by preselected simulation tasks. Interestingly, the virtual laboratory also plays a key role in increasing student collaboration and social interaction during the laboratory sessions, which are discussed in Section 2. It is the authors belief that blending strategies and technology-driven utilities as discussed in this paper could be applied to other comparable cases as well; especially, if similar shortcomings as in this study are observed.

1 THE OLD LABORATORY WORK AND ITS IMPLEMENTATION

In this section, a traditional yet educationally instructive water heating laboratory work is presented. The purpose of the work is to demonstrate fundamental feedback control concepts and basic features of feedback controllers with the help of predefined laboratory experiments. The experiments are executed using an automatic water heating system and a process monitoring computer. A single session has been implemented using groups of 3, which require 80–100 groups per single course implementation. The duration of a lab-session is 60 minutes, and one teaching assistant is reserved per one group. Therefore, the laboratory sessions demand between 80 to 100 hours of contact teaching and room reservations, which make the work relatively consumptive. The laboratory sessions have intensively been conducted group after group during the first three weeks of the course. The work has been divided into two parts; namely, to prework and to actual laboratory experiments, which are shortly discussed in the following subsections.

1.1 Prework

The preliminary work is composed of a reading part and a task part. Students are expected to read selected parts from written laboratory instruction, and to do several pen-and-pencil rote calculations before entering into the laboratory. The reading part includes, e.g. the description of the laboratory equipment, elementary knowledge of control systems, and simple controller tuning rules. During the last several years, the prework has been relatively unsuccessful: Students have experienced the content to be too difficult to grasp, widespread, and detail-oriented, which, according to students' experience, indicate inaccessibility of the material. As a result, the instructions are seen unintelligible, and therefore, the calculations of the task part are often left undone.

It seems that students are unable to form consistent links between mathematical content and the attributes of the physical system using the broad written material only. Also, some questions are not directly related to the actual laboratory tasks, which tend to alienate students from the context. Furthermore, the results of the prework are not necessarily reflected with the actual laboratory experiment, which leaves the prework unattached at the student's point of view. Students are also aware that they are allowed to enter into the laboratory room without solving the math problems of the task part. Consequently, the majority of the students do not complete the prework, and they enter into the laboratory totally unprepared. Unpreparation complicates the proceeding of the actual experiments, which may translate to decreased learning outcome.

1.2 The actual laboratory experiments

In this subsection, the implementation of the actual experiments is presented. The water heating equipment and process monitoring computer are arranged side by side as indicated in *Fig. 1*, respectively.

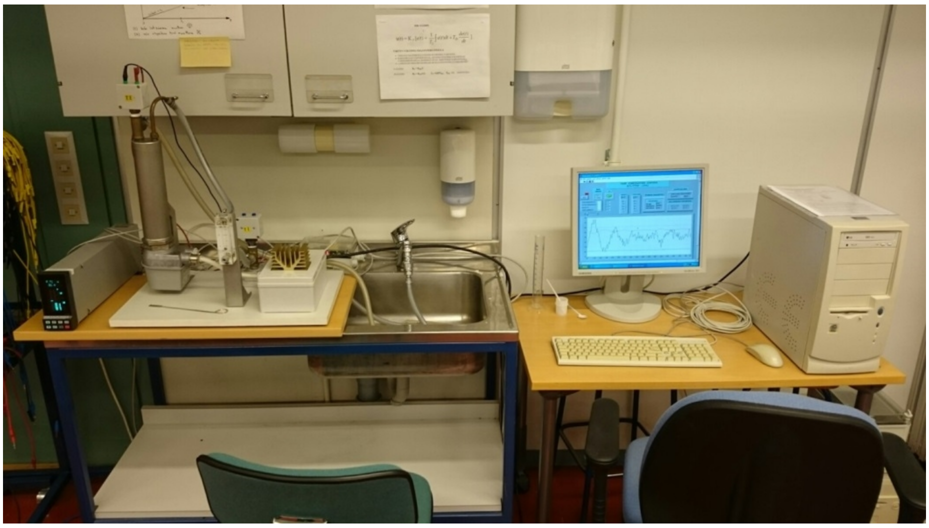

Fig. 1. Water heating system (left) and process monitoring computer (right).

Students sit in front of the desktop, where they configure the controller, change controller tunings and perform experiments using a graphical user interface provided. The outcome of each experiment is graphically displayed on the process monitoring computer. The experiments illustrate some basic features of P/PI/PID (Proportional/ Proportional-Integral/Proportional-Integral-Derivative) controllers and their simple experimental-based tuning procedures. Also, fundamental concepts of control systems such as stability, actuator saturation, regulation, and servo control are demonstrated.

The 60 minutes has been allocated as follows. First, the answers to the prework are discussed. Then, students are expected to identify, e.g. sensors and actuators which are used for feedback control. In what follows, the teaching assistant usually gives a short introduction to the forthcoming experiments. These initial steps may require up to 15 minutes to complete, which leaves 45 minutes to the actual experiments. Unfortunately, students are rarely able to assimilate all relevant information provided by the on-site initialization only. Therefore, some reviewing is sometimes compulsory during the experiments in order to maintain meaningful learning episode.

However, additional reviewing tends to slow down the proceeding of the work, which take several additional minutes off from the actual experiments. Because time is critical factor in the experiment, the teaching assistant needs to decide whether he/she will increase his/her own contribution in order to accelerate the workflow, or he/she must accept that not all tasks are completed by the students which cast shortcoming in terms of substance. If the assistant increases his/her contribution, which is the usual choice, then the students are really not doing the tasks anymore, which decreases the learning experience gained. If time runs out, some of the tasks will not be completed, which leaves the work undone. Undone work has negative impact on students' motivation, because it creates feelings of failure and futility.

In conclusion, the author feels that failed preparation together with a too short time span allocated for students to complete the experiment themselves, as well as teacher-centred instruction are the main reasons for unsatisfaction. Therefore, the author decided to reformulate the pedagogical approach of the laboratory work using blended and flipped learnings. Also, student-centred learning, active student collaboration and social interaction are fostered as central parts of the experiment. The new approach along with its implementation are described in the following section.

2 THE NEW LABORATORY WORK AND ITS IMPLEMENTATION

The author started the innovation process by raising a collection of questions, which were used to redesign the teaching and learning relationship of the laboratory work. The questions obtained are listed below.

How to

1) deliver the introduction of the experiment in a more accessible way?
2) increase time and effort that students are willing to invest in preparation process before they enter into the laboratory?
3) strengthen the link between the prework and actual experiments in order to make the overall learning episode more coherent at the students' point of view?
4) release more time for students to execute the actual experiments themselves?
5) increase student cooperation and social interaction during the experiments?
6) offer a fascinating learning experience, which would make the laboratory work more enjoyable among the students?
7) establish a positive learning environment within the laboratory room?
8) exploit blended and flipped learnings in order to fulfil the demands in 1–7?

The author would like to note that there has been pressure to reduce the overall costs and resources allocated to contact teaching owing to the decreased resources available. Therefore, an additional design constraint is added as part of the innovation process: How to reduce the total implementation costs of the laboratory sessions?

In contrast to the old laboratory experiment, the author decided to double the group size to 6 students, and, at the same time, increase the duration of the experiments by 30 minutes. As a result, the total contact teaching was supressed to 60–75 hours, which reduce the total implementation costs by 25%. Nevertheless, larger group size allows reorganization of the whole learning episode, as well as it allows redefinition of the roles of students and teacher. The author decided to split the group of 6 students into two collaborating teams consisting of 3 students, which, according to literature, is an optimal group size as regards to interaction and mutual cooperation between the individual members [6]. In what follows, the teams and their roles are discussed in Subsection 2.2, whereas new prelab activities using the teaser video and virtual laboratory is presented in Subsection 2.1.

2.1 Prework

The author decided to supplement written instructions with a short teaser video, and include the video as part of the prework. The main role of the video is to allow a remote visit to the physical laboratory before students actually enter there. The teaser video delivers visual information from the laboratory equipment when it is fully operational, and hence, a quick overview is naturally provided. The video includes close-ups of each physical device, i.e. the controller, sensors, actuators, and flow-through piping. The video is enhanced using Camtasia Studio and its callouts, which helps students to pay attention to the key components of the water heating system. Thereby, students are expected to identify all components, devices and their physical causation affecting the water heating using the information provided by the video and its callouts.

The author also created a virtual laboratory; namely, a Matlab-Simulink simulator, which contains a mathematical model of the laboratory equipment and their interconnections within a block diagram representation. The simulator can be used to predict the dynamic behaviour of the water heating system in a timely fashion manner. It can also be used to find control modes and their tunings, which could be suitable for the real closed-loop heating system. Furthermore, the simulator enables students to virtually observe several physical quantities and their curvatures which cannot be observed nor displayed by the physical devices in the laboratory room.

The simulator is shared to the students as a part of the prework. The students are expected to carry out predefined simulations, which instantaneously display graphical information about the operation principles and causal connections of the water heating system. As a result, the preparation of the students can further be strengthened, because the simulations develop physical insight and intuition. Interestingly, some students seem to perform additional simulations, which are beyond the scope of the prework. Hence, students use the virtual laboratory as a subject for their own active research, and they are trying to find answers to questions set by themselves. The author feels that such observation demonstrates effectiveness of active learning [7-8] and learning by discovery paradigms. Sometimes additional simulations and emerging questions establish fruitful discussions between the students and teacher. In this way, students can have own impact and contribution to the learning episode itself, which generally make learning more meaningful.

The new prework includes parts from the same reading material and theoretical tasks as the old work did. However, students accomplish those tasks at higher success rate than previously. The author feels that increased success is mostly resulting from technology-driven blended and flipped learning approaches adopted, which strengthen the preparation process of students in accessible and concrete way. They may also positively affect to students' attitudes towards learning, because of the research-based framework provided. Furthermore, new prelab activities are somewhat more attractive compared with the written laboratory instructions, and hence, students are willing to spend more time for their own preparation, which lays the foundation for successful activities in the laboratory room as well. Next, the new implementation of the on-site laboratory activities using collaborative student teams is discussed in Subsection 2.2.

2.2 The actual laboratory experiments

As stated in Section 2, the group size was enlarged to 6 students which allow reorganization of the roles of the students. The author decided to split the group of 6 students into two collaborating teams; namely, to a simulation team and to a testing team. The testing team is working with the actual equipment, which was depicted in *Fig. 1*. However, the author built another desktop beside the water heating system, which is depicted in *Fig. 2*, respectively.

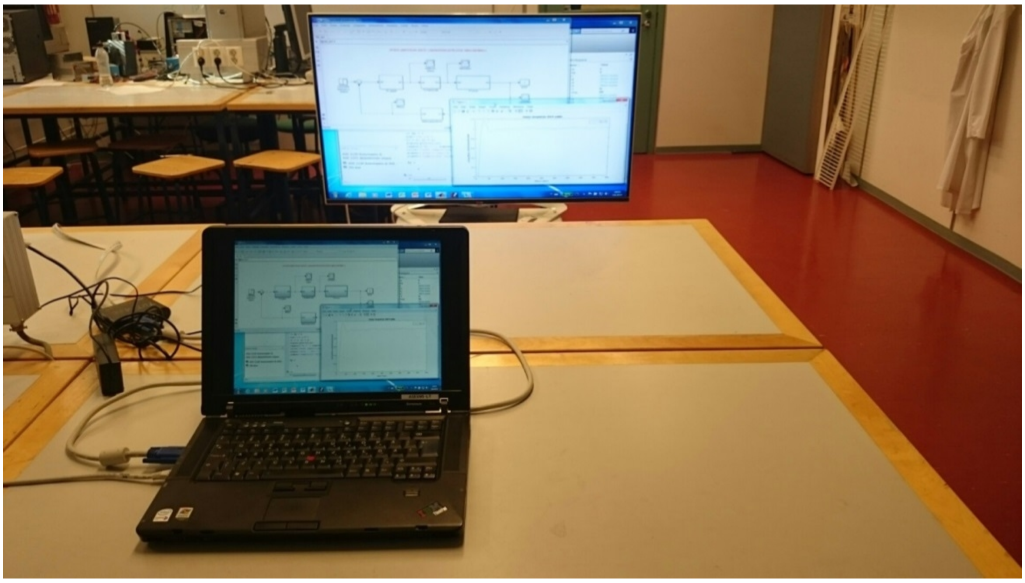

Fig. 2. The work desk of the simulation team and a large external display.

The idea of the new layout is that students can run the physical water heating system and the virtual laboratory in-parallel. The layout also enables students to do teamwork and communicate with each other cooperatively within the own team, as well as collaboratively between the teams. It should be noted that recent research on blended learning suggests that teachers should encourage students for more participation, and to find ways for creating social interaction through collaboration in order to create a positive learning environment [9].

At the beginning of the experiment, the teacher does the grouping of students, as well as checks the answers of the prework. Because students are well-prepared and the preworks are more completely done, the initial phase takes only few minutes to complete, which leaves more time for the actual experiments. The first actual task is to test simulation-based findings from the prework using the actual equipment. Hence, the prework has been linked to the beginning of the actual work in an apparent way, and it therefore provides an efficient start for the forthcoming experiments. Students find it interesting to test their own, although simulation-based, results on a real device.

Both teams have several similar tasks during the laboratory experiment. However, the simulation team receives their results much faster than the testing team. Hence, selected functions from the simulator has intentionally been omitted, so the simulation team needs to build several additional blocks within the virtual laboratory using mathematical equations provided. Building more comprehensive model keeps the simulation team busy, while the testing team performs the actual experiments.

More importantly, some tasks have formulated such that the testing team must seek support from the simulation team. The testing team may also ask the simulation team to observe physical quantities which are only available within the virtual laboratory. Such events “force” teams to communicate and to do team work, which create positive interdependence between the teams. In addition, both teams are required to present their findings to one another after each task using a large external display depicted in *Fig. 2*. Teams are encouraged to discuss their results in a collaborative manner, and to make thoughtful justification between the simulation and experimental results. Such operation model drives the groups towards self-regulation and independence. As a result, the role of the teacher is steered towards mentor-like activity, and therefore, the teacher-mentor can use his/her own expertise to strengthen the knowledge level of the students via professional facilitation. The author would like to pinpoint that such on-site facilitation upgrades the effectiveness of contact teaching. In conclusion, traditional face-to-face instruction is very important in flipped and blended learning settings in order to establish a powerful learning environment, which is able to outperform traditional teacher-led classroom.

Because the duration of the experiment was increased by 30 minutes, additional questions were formed, which link the prework, simulations, and the experimental results in an educational way. Examples of such questions are: Why simulation model is useful for control engineer? Why the results obtained from the simulation model and actual experiments differ from one another? Justify your answer theoretically and practically. What was the most distinct result in this experiment? Are there any risks involved, if justifications are based only on the outcome of the virtual laboratory? Propose a control strategy which is able to mitigate the effect of changing inflow temperature to outflow temperature. How would you implement the chosen strategy? What is the effect of sensor location in such strategy?

Since the initiation of the new laboratory experiment, it is interesting to observe that students are capable of answering the aforementioned questions relatively satisfactory without using direct help from the teacher. Improved answering indicate students’ increased ability to think out of the box. Interestingly, now students generally ask more questions than previously, which, at least, imply willingness to learn more. It may also indicate that learning has taken place in a meaningful way, which tend to raise interest towards learning. The collaborative nature of the new implementation may encourage students to activate themselves, and hence, ease the awkwardness of asking questions and discussion in general. Furthermore, socially active atmosphere brings teachers and learners together, which helps to create positive learning environment.

However, it should be emphasized that the new laboratory work is more complex compared with the previous one, and hence, teachers also need to be more prepared than before. Usually, teachers of laboratory experiments are undergraduate students themselves, and their skills, experience and expertise may not suffice to handle more complex group work unless properly acquainted. Since students are more active during the learning episode, the teacher responsible is faced not only with more questions, but also with more advanced questions, for which a student-teacher may be unable to answer satisfactorily owing to his/her own immaturity. It is therefore crucial that the teaching assistants are carefully introduced before the sessions, which, on the other hand, may require additional resources from the personnel. The author suggests that a tutorial session combined with a video, in which an experienced teacher conducts an authentic laboratory session, could significantly help assistants to carry out their own preparation process as well as improve their skills development. As a result, the new laboratory work could be more rewarding for the teaching assistants too compared with the teacher-centred instruction, which follow the same predefined path time and again.

3 DISCUSSION

Students have been unexpectedly satisfied with the new laboratory work, and much more positive student feedback is now obtained as an outcome. The feedback has mainly been gathered by oral discussion at the end of each session as well as through anonymous online course feedback system. At the students' perspective, the most frequent positive responses are related to student-centredness, learning by doing, concrete and interesting tasks, and especially to effective guidance delivered by teachers, and supportive atmosphere. Although, some students are asking for a summary of the key points of the work, which they could later use to reflect their own learning.

At the teachers' perspective, the new laboratory work meets the expectations of the innovation process relatively well. For example, preparation of students has been successful, which has translated to improved proceeding of the actual experiments. More advanced tasks, which require deeper level of understanding have been added, and hence, the standard of the work has been raised. Also, increased social interaction and collaboration between the student teams develop learner autonomy and independence, which allow students to learn from one another. Generally, learner-centred approach forces students to take more responsibility of their own learning, and it increases the time spent towards educational activities. Increased timely investment tends to improve learning outcomes, which eventually translates to better grades, and finally, to better overall satisfaction. It is the authors belief that flipped and blended learning approaches together with technology-driven utilities better serve the needs and expectations of present-day students compared with the traditional teacher-led classroom. The reorganisation of the roles of student and teachers may also positively influence students' attitudes towards learning and their commitment to educational activities, because students have more own impact on the learning episode itself, and because of the presence of an approachable teacher, which is able to support the learning processes of students.

4 ACKNOWLEDGMENTS

The author would like to thank anonymous reviewers for their helpful comments, which improved the theoretical background and quality of this paper. The author would also like to thank Professor Matti Vilkko for his positive attitude and timely investment towards teaching development. Furthermore, the author is grateful to Professor Mika Valden for our fruitful discussions as regards to teaching, engineering education and technology.

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