E-learning on the lab with lab education software.
Deeper learning & more efficiency?

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ABSTRACT

In preparing and executing labwork, students experience cognitive overload in understanding their lab work and keeping an overview of the lab experiment. In addition, giving just-in-time feedback to students causes peak loads in working hours for lab-teachers. We investigated the additional value of an inquiry based lab education software tool LabBuddy® on the learning and preparation of students and the peak loads of the lab-teachers.

In LabBuddy®, students co-operated in groups of 4 to prepare a (visual) block diagram representing their protocol and plan of approach for Creating Biological Tissue. Students were in their 2^{nd} yr bachelor within the Biomedical Engineering programme. Students were further prepared by videos and pictures in LabBuddy®. The lab-teacher gave in-line feedback on students' documents. On the lab, tablets and computer screens were available so that students could access their protocol, answer questions and make notes in the digital labjournal.

Data was collected by observations on the lab, focusgroup sessions (with teaching assistants), a questionnaire (41 items) and by comparing students' final test results (70 students). Compared to last year (all preparations and notes on paper), students now feel better prepared for the lab work, have a good overview of the whole experiment while working on the lab and make more notes on their observations. The final reports are improved as students now follow more closely the research cycle. The peak load in working hours for students and labteachers is decreased. Students find LabBuddy® an intuitive system and would like to use the system for other labwork too.

1 INTRODUCTION

The notion of students managing their own learning process is embodied in the concept of Student Driven Learning (SDL) [1]. At our University of Twente, the programmes seek to develop in our students a wide range of skills, and to provide them with the opportunity to create their own development and learning experiences through multiple projects [2]. The SDL projects require students to undergo a mind shift from being a following student to becoming a student who is able to learn entirely in a self-directed manner [3].

Within the programme of Biomedical Engineering, students have quite a lot of practicals. Practicals are used to show students the practical applications of the theory and to learn them the practical skills of performing lab work. One of the practicals is the challenging and complex practical “Creating Biological Tissue” in which students differentiate human stem cells to create fat, bone or chondrocyte cells. The project is not only known for its complexity, but also for its high cognitive load for students and the high work load for teachers. Teachers notice that students ask quite some basic questions on the lab, showing that students have problems in understanding what they have to do (e.g., what is a filtrate? Where can I find the microscope?) and in keeping an overview of the lab work. [cf Johnstone [4]] Therefore, teachers would like to develop ways in which the cognitive load would diminish and students could spend more time on higher order questions.

Abeysekera & Dawson [5] define the flipped classroom as “a set of pedagogical approaches that a) move most information-transmission teaching out of class, b) use class time for learning activities that are active and social and c) require students to complete pre- and/or post-class activities to fully benefit from in-class work”. Chittleborough at al. [6] showed that the flipped classroom setting could be applied to laboratory practicals. In preparation for practicals pre-lab activities can help [7]. Harrison et al. [8] used videos, simulations and quizzes in The Dynamic Laboratory Manual. Rodgers et al. [9] discovered that pre lab videos made students better prepared for lab work. Diederen et al [10] used digital assignments on research experiments. Brame [11] states that in flipping the classroom, students focus on the lower levels of Bloom’s revised taxonomy [12] (gaining knowledge and comprehension) outside of class. During class students focus on the higher forms of cognitive work (application, analysis, synthesis, and/or evaluation) being supported by their peers and instructor.

Van Den Boom & Schlusmans [13] state that giving feedback is one of the learning functions, as it is important to give students insight in their learning process and achievements. Van der Kolk [7] found out that in practicals supervisors often had to spend quite some time on figuring out what students meant, and felt it was difficult to give sufficient adequate feedback on the plans of approach.

Van der Kolk [7] developed LabBuddy®, an e-learning tool that supports learning in laboratory classes. In this e-learning tool students are forced to prepare themselves properly for the lab work: students need to answer questions on the theory of the lab experiment, and need to come up with a plan of approach for their practical. To support students in preparing themselves for the lab environment and lab tasks, photos and videos are available in LabBuddy®. In their preparation, students make a visual overview (block scheme) representing all the steps in the experiment to be executed.

LabBuddy® is an online tool, so that students can collaborate in groups and work on the same plan. The teacher can approach the scheme too, and give feedback (using digital post its). During lab work, students can approach their block scheme, follow the steps and make notes of their observations in a digital labjournal. Using the e-learning tool LabBuddy®, might help students to reach higher levels of knowledge and skills, and might diminish the work load for the teachers.

In this paper we focus on "How can an e-learning tool support the practical at BioMedicalEngineering at the University of Twente". In the sub questions, we focus on learning, collaboration of students and the workload of the lab teachers:

- How does LabBuddy® contribute to deeper learning (knowledge and skills)?
- What is the effect of LabBuddy® on group collaboration?
- How does the use of LabBuddy® influence the workload from labteachers?
- What are the experiences from students in working with this new tool (functional evaluation)?

In section 2, the relation between the research questions and the methodology will be presented. This is followed by the presentation of the results in section 3, while section 4 closes off with the conclusion and discussion.

2 METHOD / RESEARCH QUESTIONS

2.1 Context

Participants were 70 2nd year Bachelor students from BioMedical Engineering at the University of Twente. Students were divided into 16 projects groups. All groups had to prepare and perform an experiment in which they had to create and analyse biological tissue from stem cells. The e-learning tool LabBuddy® was used to support the learning process, both in the preparation and execution phase of the experiment. In total the project is 4 EC (≈ 110 hrs), of which around 1.5 day lab work.

2.2 LabBuddy®

LabBuddy® is an e-learning tool that supports students in preparing their labwork and keeps them focused while working on the lab [7,14]. In LabBuddy® it is possible to design and prepare the entire experiment in visual blocks. Figure 1 shows part of an overview of the design of an experiment.

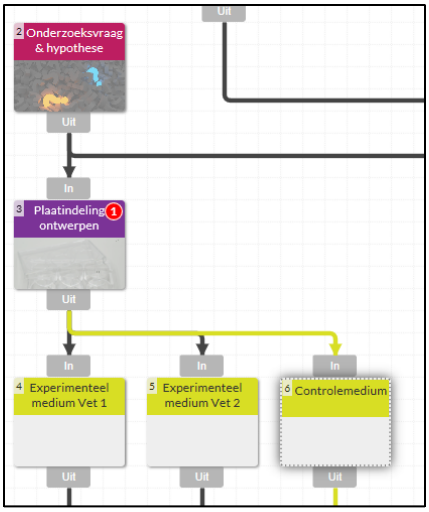

Figure 1: Visual block scheme of the design of an experiment (e.g, a block with the research question (red block), overall experimental design (purple block) and the experimental conditions in the yellow blocks).

In the implementation of LabBuddy® at the University of Twente, the following elements were added:

- *Questions* on domain knowledge, *videos* showing complex activities and *photos* showing the actual equipment to prepare students for the lab.
- All *protocols* were already available in LabBuddy® in visual blocks, so that students only had to select the appropriate protocols in the right order (see also Figure 2).
- A *digital labjournal* was implemented so that students could make notes on their observations.
- *Digital post its*, so that teachers easily could 'stick' their feedback to the visual block scheme and the plan of approach.
- Regarding *hardware*, tablets and computer screens were available so that students could access their protocol, answer questions and make notes in the digital labjournal. Students used large screens to keep an overview of the entire

experiment. The tablets were used to read the protocols. For (biological) safety reasons, students were not allowed to use their own equipment on the lab.

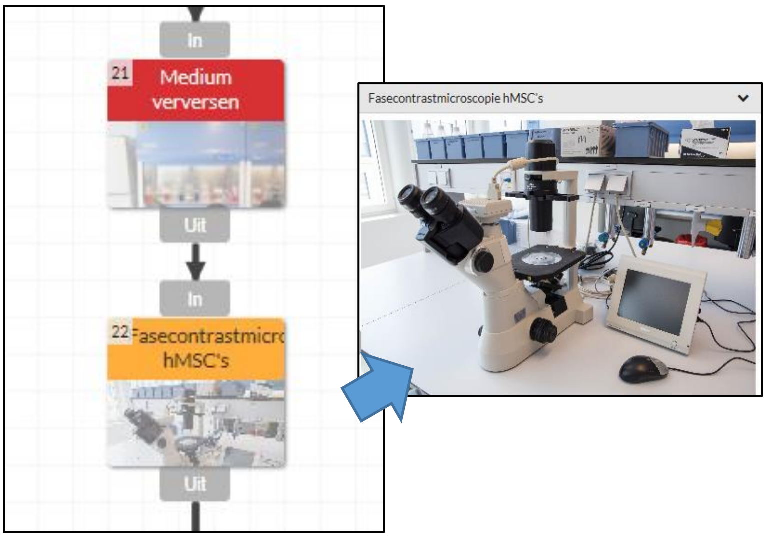

Figure 2. Part of the visual block scheme. After growing the cells, students have to refresh medium (red block contains protocol), and check the condition of the cells. Student use phase contrast microscopy (the orange block contains a picture of the microscope and a video on how to use it) to check the condition of the cells.

2.3 Research questions

Multiple methods and instruments were used to answer the research questions. The first research question was answered by analysing the items in the final exam; the expectation was that students would score higher on these items, as all students had to answer questions in preparing for the lab. In addition, the final report of the research experiment was analysed to see whether the quality of the report would improve. As in LabBuddy® students have to follow the research cycle more closely, we expected an improvement. Finally, student behaviour and their questions posed to the tutors were observed and analysed. It was expected that students would be better prepared and therefore would ask less low level questions. Lab teachers were asked to register their working hours, especially the hours on giving feedback (as that process caused peak loads for teachers). A student questionnaire (41 items) was used to measure student appreciation of LabBuddy®. Table 1 shows an overview of the research questions and methods.

Table 1: Overview of research questions and research methods**.**

Research question	**Comparison** LabBuddy® group to last year's group in which LabBuddy® wasn't used.
1) How does LabBuddy® contribute to deeper learning (knowledge, skills)?	a) Compare grades on written test related to experiment. b)Observation/ focus group: Compare the type of questions asked during labwork. c) Analysis of final report: Description of the research cycle.
2) What is the effect of LabBuddy® on group collaboration?	Student questionnaire: Student evaluation on group work. Observation / focus group: on student collaboration.
3) How does the use of LabBuddy® influence the workload from lecturers?	Registration of working hours.
4) What are the experiences from students in working with this new tool (functional evaluation)?	Student questionnaire on experiences.

3 RESULTS

1.How does LabBuddy® contribute to deeper learning (knowledge and skills)? The research question is answered by comparing scores etc. with performance of previous cohorts of students (no e-learning tool).

a) Comparison of scores on final exam related to the experiment. In comparing the scores on items, related to the experiment, in the final exam (2016-2018) we found no significant difference between the scores on the exam (2016 and 2018; t=1.783, P= 0.07; n=70).

b) Comparison of types of questions posed by students at the lab.

In an observation on the lab and a focus group session with teachers and teaching assistants we found that, compared to last year, students asked less knowledge based questions (e.g. 'What is filtrate?') and less task related questions (e.g. 'How does this device work?'). Based upon the observations and the focus groups session with lecturers we can conclude that students were better prepared for lab work and were more independent than before.

c) Does the use of the research cycle in the final report change?

Based on the experiment, students have to write a final report in which they follow the research cycle (research question, hypothesis, methodology, results, conclusion). In 2017, so before LabBuddy®, lab teachers gave advised to use this cycle and refer back to the research question in writing the conclusions. However, only 27% of the reports contained this connection between conclusions and research question. LabBuddy® helps in following the research cycle and explicitly stimulates students to look back at the research questions when drawing conclusions. Apparently, this helped students to improve their report as now 88% of the reports contained a connection between final conclusion and research question.

2. What is the effect of LabBuddy® on group collaboration?

In lab observations, the authors noticed that students collaborate well within LabBuddy®: Large screens are used to look at the visual block scheme: students stand in front of screen, discuss their experiment, divide tasks and continue working independently. Hand held tablets are used to read the protocol and/or to process notes and questions. All students in the group are active (no freeriding behavior observed) and can explain the experiment. The student evaluation (table 2, item7) showes that 61% of the students thought that their group members equally contributed to the project. Because of some technical issues we realized that large screens and sufficient WIFI capacity is important.

In a focus group session with tutors, we found that one teaching assistant was quite negative about LabBuddy® and its usefulness: he had no interaction with the group as his students followed the instructions more closely. Lecturers, however, were positive about the interaction with the group and found that the block scheme could be used as a starting point for group discussions.

3. How does the use of LabBuddy® influence the workload from lecturers?

Assessing and giving feedback on the student products is time consuming. Last years, that was especially true for the plan of approach. Lecturers and students experienced a peak load in giving and receiving feedback on these plans. This year, all feedback was delivered through LabBuddy®. The block scheme helped to give to the point feedback at an early stage, which reduced moments of stress before the start of the practical.

In comparing the registered worked hours we found that the feedback process took around 40 hrs in recent years. This year, these hours were reduced to 14 hrs.

4. What are the experiences from students in working with this new tool (functional evaluation)?

In a final evaluation questionnaire (41 items, 5 point Likert scale), students were asked for their opinion on several aspects of working with LabBuddy® (preparation, background information in LabBuddy®, cooperation, overview of the project, feedback, time investment, labjournal and manual). The main results can be found in Table 2 (41 students completed the questionnaire).

Table *2:* Results student questionnaire (question, mean score on 5 point Likert scale, standard deviation and percentage of students that answered 4 or 5 on that item).

Preparation	**Mean**	**SD**	**≥4 (%)**
1. The preparatory questions from LabBuddy® made me feel well prepared for the project.	3.8	0.8	71
2. The background information that was available through LabBuddy® fitted in well with my prior knowledge.	3.5	0.8	54
3. The videos helped me to better understand the methods and techniques used.	3.5	1	56
4. The use of Prepare mode in LabBuddy® ensured that I had (more) confidence in the correct execution of my experiment.	3.6	0.9	63
Collaboration			
5. LabBuddy® makes the exchange of information between group members easy during preparation.	3	1.2	42
6. In communication with the tutor, LabBuddy® made it easier to exchange information.	3.2	1	48
7. Everyone in our group contributed more or less equally to the project.	3.5	1.1	61
Working on the lab			
8. Because of the visual block diagram I always knew what I was doing in the project.	4	1	81
9. The questions in Work Mode provided more insight into the project.	3.8	0.7	78
10. The photos of techniques and equipment made sure that I could work more independently.	3.3	1	54
11. By using LabBuddy® I had the feeling that I could work (better) independently.	3.7	0.8	71
Feedback			
12. The feedback on the open questions helped me to better understand the project.	3.3	1.1	51
13. The feedback from LabBuddy® on our Schedule helped our group to come up with a good schedule independently.	3.5	1.1	68
14. It was handy that the teacher could add the feedback to our schedule in LabBuddy®.	4.3	0.7	93
15. In the preparation I found it useful to get automatic feedback from LabBuddy®.	4	1.1	80
16. The automatic feedback helped me to better understand the project.	3.4	1.2	61
17. During the project, automatic feedback on, for example, the calculations of dilutions was useful.	2.8	1.2	29

Labjournal			
18. In general, I like being able to make digital notes at a practical.	3.5	1.1	61
19. In LabBuddy® I was able to write down my observations.	3.6	1	63
20. In LabBuddy® I was able to write down my calculations.	2.6	1.1	24
Practical manual and future			
21. LabBuddy® is a good alternative to a paper practical manual.	4.1	0.6	73
22. In other modules (eg M11) I would like to use a digital learning environment, such as LabBuddy®	4.1	0.6	88

The results of the questionnaire show the following:

- *Preparation:* In general, a majority of students felt better prepared because of the LabBuddy® activities (table 2, item 1 to 4). For example, 71% of the students felt that the questions prepared them for the project.
- *Feedback / workload*: The survey showed that feedback through LabBuddy® worked out well. 93% of the students found it handy that the teacher could add feedback to their visual block scheme in LabBuddy® (table 2, item 14) and 80% found it useful to get automatic feedback (on MC-questions) (table 2, item 15), The automatic feedback on calculations (e.g., calculations on cell density) scored really low on usefulness (29%, table 2, item 17). Most likely this was due to too small error margins on calculated answers. For subsequent practicals this can easily be adjusted.
- *Labjournal:* The new digital labjournal function worked out well for making digital notes (61%, table 2, item 18) and observations (63%, table 2, item 19) at the practical. Students preferred to make the calculation on paper (24%, table 2, item 20).

4 CONCLUSION AND DISCUSSION

In this paper, we investigated “How can e-learning tool support the practical at BioMedicalEngineering” at our University of Twente. We focussed on student learning and collaboration. As giving feedback caused peak loads for teachers, we investigated the feedback process and working hours for teachers. Finally, we asked students for their opinion on the e-learning tool. In this section, we will look back at the research question, discuss the main results and give suggestions for further research.

How does LabBuddy® contribute to deeper learning (knowledge and skills)?

In the preparation for their lab work in LabBuddy®, students had to answer questions in the lower levels of Bloom’s revised taxonomy [12] and watch videos on basic lab skills. This resulted in autonomous behaviour on the lab, as students knew what they had to do [cf 11]. Neumann and Welzel [15] conclude that ‘a systematic and strategic support seems necessary to allow for an acquisition of metacognitive and content specific knowledge in open learning environments’. In LabBuddy®, our students were supported in this process by several questions and prompts for taking notes and reflection. This support helped our students to follow the research cycle more closely: in the final report, students referred to their research question while drawing conclusions on the experiments. Our functional evaluation, the questionnaire, of LabBuddy showed that students find LabBuddy® an intuitive system and would like to use it for other labwork too. This attitude towards the e-learning tool on the lab, opens opportunities for scaffolding the learning process at the lab. Within LabBuddy®, the information needed for the experiment is chunked into little blocks (see Figure 1).

Within our SDL projects (1), students take responsibility for their own learning. For learning on the lab, this process could be supported by increasing the complexity of the lab work and decreasing the amount of scaffolding: e.g., in the first year, the visual scheme and blocks are pre-defined, whereas in later years, students have to select the right blocks and structure (e.g., the experiment as described in this paper). For their final bachelor project, students could be asked to come up with their own building blocks and plan of approach. In this way, students are challenged to take responsibility for improving their research skills.

Quite some digital videos and photos from equipment on our lab, were added to LabBuddy® to support students in learning the complex lab skills. Those videos were created using the multimedia principles from Mayer [17]. Just recently, a study by Rodgers et al. [9] revealed ideas to even improve our videos.

The effect of LabBuddy® on group collaboration.

In previous years, students sometimes complained that not everyone contributed equally to the project, mostly because of the fact that those free riders did not understand the complex experiment. This year within LabBuddy®, cooperation in the preparation and during the practical phase went smoothly: students sat together, divided tasks and could continue working independently. Tutors checked whether all group members could explain the whole experiment and found no freeriding behaviour. The interaction between the project group and the teaching assistants at the lab changed. One teaching assistant thought that his interaction with project groups had diminished compared to last year and he noticed that his groups followed the instructions on their tablets more closely. Therefore, he was quite negative about LabBuddy® and its usefulness. This observation might be an interesting element for further research in the lab environment since the role of the teaching assistant might change from an expert role to a more cognitive coach as described by Wallace and Walker [16]. In a follow up our study, it might be good to have a look at the new role of the teaching assistants and how to prepare them for that role.

How does the use of LabBuddy® influence the workload from lecturers?

In our study, teachers used ‘digital post its’ to give feedback on the plans of approach (check correctness of approach, feasibility regarding labwork), on open questions and on calculations. All feedback was given within the e-learning tool LabBuddy®. Feedback could be very specific (e.g, check dilution of cells in your experimental condition) and just-in-time (as students were still working on their plan). Students easily adapted their plans based on the feedback (which makes the whole process efficient and effective). Hours spent on giving feedback were reduced with 65%, while students were still very satisfied with the feedback. Most probably, this reduction was caused by the fact that all plans of approach were easily available (via the visual block scheme), had a similar structure and all feedback could be given within the system (so no separate e-mails). All in all, this shows that the e-learning tool simplified the process of feedback, while keeping the quality high.

Functional evaluation of the e-learning tool

As was mentioned before, students found the e-learning tool an intuitive system and would like to use it for other projects as well. The third author asked for an improvement of the labjournal function in LabBuddy®, so that students could make notes digitally on all their observations. Although this new labjournal function was still a ‘pilot’, around 60% of the students were already happy with this opportunity. Most students prefer to write their calculations on paper. We did not experience any influence of this pilot on the outcomes of our study.

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