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Attempt to increase the learning outcome from laboratory exercises

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Introduction

This year (and hopefully many years to come), I have taken part in teaching a second year Bachelor course in biochemistry (“Biokemi 1”), which is a mandatory or elective course in a number of Bachelor programs (Biology-biotechnology; Food science and nutrition; Animal Science; Natural Resources; Chemistry) at the University of Copenhagen. The number of students taking the course is around 220-240. For my project in “Universitetspædagogikum”, I chose to focus on the laboratory exercises, as it was my impression from the Course responsible and the student evaluations from the previous year that this is where there was room for improvement.

In traditional university chemistry courses, we spend a vast amount of time and resources on practical laboratory exercises, as also highlighted by Wood (1996). Students also spend many hours on the practical part of the courses, as exercises are often mandatory, and reports have to be accepted – possibly as a prerequisite for taking the course exam. Reid & Shah (2007) states that “*the labour costs for 3 hours of laboratory teaching may well be around 15 times the costs for a one hour lecture for 100 students. Is the learning gain 15 times greater?*”. I don’t think the equation is as easy as to only look at the learning gain, as it is also a matter of learning aims. In my mind though, the important question is if it is possible to increase the learning outcome from these exercises, as the time spend not always seems to result in an adequate learning outcome.

I find it very motivating to work with this subject: how to increase the learning outcome from practical laboratory exercises, which was also the topic for the pre-project "Learning from Lab Work", that I conducted together with four other participants of this course. In this pre-project we interviewed 7 students about their experiences with laboratory exercises, and some of the recommendations were to have laboratory manuals as open as possible, to have clear aims, to "force" the students to prepare something before the exercises – all means to increase the learning outcome. Furthermore, it was recommended to repeat the theory in different ways, and to prioritise time to ask questions to the students and create "discussions" between students and teachers. Finally, it was emphasised that "less is more", meaning that the students would prefer fewer exercises, or exercises with less information, where they could actually grasp the essential aims of the exercises, rather than an overload of information and exercises.

For the Biochemistry 1 course, I was assigned to be responsible for one of six laboratory exercises. My exercise ran parallel with another exercise during the first two weeks of the block (in total, the exercise was conducted 10 times during these two weeks, with approximately 24 students each time). The exercise "Ion exchange of ribonucleotides" was allocated 4 hours, as for all the laboratory exercises. The exercise usually takes 3-4 hours to conduct, and it was not possible to allocate extra time. I had no prior experience with teaching this exercise, so the changes I made were only based on my personal experiences with the exercise, the pre-lab questions and the report scheme that is to be handed in. It was not possible to change the exercise itself, neither the laboratory manual. Therefore, I chose to make some changes in connection with the theoretical preparation for the exercise, and I decided to use 30-45 minutes in the beginning of the practical exercise. Here, it was my plan to have a short theoretical session before starting up in the laboratory. I chose to do this, as it is my impression that students often use most of their energy in the laboratory focusing on conducting the experiment as described in the manual. They are not focusing on the part of learning from the exercise while being in the lab. My focus was to try to move the learning into the lab, thereby also possibly raising the motivation and increasing the learning outcome.

Method

I decided to add some extra theory about the analysis methods that are being used in the exercise (ion exchange chromatography and UV spectroscopy), as well as moving some questions from the report scheme to the pre-lab questions. My idea with having a theoretical session before the practical exercise was to have students actively participating in a discussion about the choice of methods for the exercise. I chose to do this because I wanted to engage, and increase the interests of, the students in order to enhance their “intrinsic” motivation and thereby increasing deep learning (Biggs and Tang, 2007).

In the exercise, a mixture of four nucleotides is separated by use of ion exchange chromatography, and following identified using UV spectroscopy. The added pre-lab questions concerned the structures of the nucleotides (own drawings and identification of groups responsible for acid/base characteristics) and drawing of Bjerrum-diagrams for the four nucleotides.

The theoretical session took place in an empty laboratory, with only a small blackboard. My intention was to have a dialogue with the students by raising some questions concerning the practical exercise, but related to the theoretical understanding. The questions I prepared to use for the dialogue were:

- What kinds of column chromatography do you know?
- Could we have used any of these to separate the nucleotides, and why/why not?
- Could we use both cation exchange and anion exchange chromatography?
- At what pH do we apply the sample? And at what pH can we expect the nucleotides to elute?
- How can we detect that we have compounds eluting from the column?
- Should we measure UV at 254 nm or 280 nm?
- How can we use UV to identify the different nucleotides eluting from the column?

And some more practical oriented questions as:

- How do you apply the sample to the column?
- Why is it important to wash with water before elution?

With these few changes, I hoped that the students would gain a greater understanding of the exercise while doing the actual exercise in the laboratory, thereby also achieving a deeper learning of the theory over time. With the additional theoretical introduction, it was my wish to draw more focus on the methods used, as it is the methods that – in my view – are the most important learning outcome from the exercises at this point of time in their education (second year).

The theoretical session was introduced on 3 days during the second week, and it changed somewhat over these days. The first day (Thursday), it took approximately 25 minutes, and was mainly a theoretical session as described above. The session included 5 minutes at the end, where I gave some practical information, in the same way as I would usually do in the first 5 minutes of the practical exercise. As the students following were as confused as without the theoretical session (due to an insufficient description of the experimental setup in the laboratory manual, and a lot of unknown equipment), I decided to extend the session the following day (Friday, 35 minutes). I brought an experimental setup and at the end of the session I went through all the equipment and explained what it was and how it should be connected etc. This seemed to have a slightly positive effect on the following start-up in the laboratory, though there was still a lot of confusion. On Monday, I further extended the presentation with the drawing of a workflow on the blackboard, in order to illustrate how different tasks could be initiated at the same time, and what tasks should be done at which point. This Monday, the session went on for approximately 45 minutes.

All students who had been exposed to my extra theoretical session were given a questionnaire the following week in the laboratory. I chose to hand out the questionnaire the following week, because I wanted the students to have had time to do the reports (where they work more with the theory) before filling out the questionnaire. The questionnaire comprised 13 questions (see Appendix).

Results

It was easy to see that the students were not used to partake in a dialogue. Most students seemed uninterested in the beginning, and it became more difficult to obtain a dialogue, than I had expected. Some students stated that they had not solved the pre-lab questions as they did not know how to. Instead of creating a dialogue with all the students, I asked them to discuss a question in smaller groups. This seemed to create more activity and discussion about the question, and more students were afterwards willing to come up with an answer. The sessions never reached a point where the students came up with a lot of questions themselves. This can be interpreted in different ways. The questions and theory might have been too easy and too obvious, or the students were not puzzled enough about the theory, in order to seek answers to questions.

The results from the questionnaire can be found in the Appendix. Overall the students responded positively to the theoretical session, but approximately half of the students found that we spend too much time on this session. Around 40 % of the students answered that they had only done part of, or none of, the pre-lab questions. These questions were quite central for the theoretical session, and I did not spend time going through these as it would have further prolonged the time spend on the theory. Additionally, it was not until I received the questionnaires, that it became clear to me, how many might have had a lacking foundation for the theoretical discussion. This, of course, can to some extend explain the unwillingness to participate in discussions, but I also think it is a matter of what the students are accustomed to, or not, from earlier courses.

Approximately 2/3 of the students found that they had a better theoretical understanding of the exercise after the theoretical session (see figure 5.1 and Appendix) compared to the other practical exercises they had conducted. This result from question 8, and the results from the following questions 9-13 (see Appendix), are difficult to evaluate, as I do not have results from those students who did not have extra theoretical session. It would have been valuable though if I had given questions 8-13 to all students, as this could have shown a possible effect from the theoretical introduction.

According to my own observations from the laboratory exercises, the theoretical session did not seem to influence the way the students worked in the laboratory afterwards. They were still confused about the unfamiliar equipment, and the insufficient manual description of how to start up the experiment still caused the same amount of questions asked, even on those days when I had given a more thorough introduction to the practical work (i.e. Friday and Monday). As my main aim with the session was to increase the theoretical understanding, this observation should not be given too much focus. A better theoretical understanding could be expected to have a positive effect on the report schemes, but when judging from the report schemes that were handed in from the students, I could not see any positive effect, rather a negative effect could be seen (based on how many reports were approved in the first round).

The students seemed positive about my initiative with the theoretical session before the laboratory exercises, even though they did not actively participate as much as I had hoped for. I am not convinced, though, that it had a positive effect on the theoretical understanding. This observation

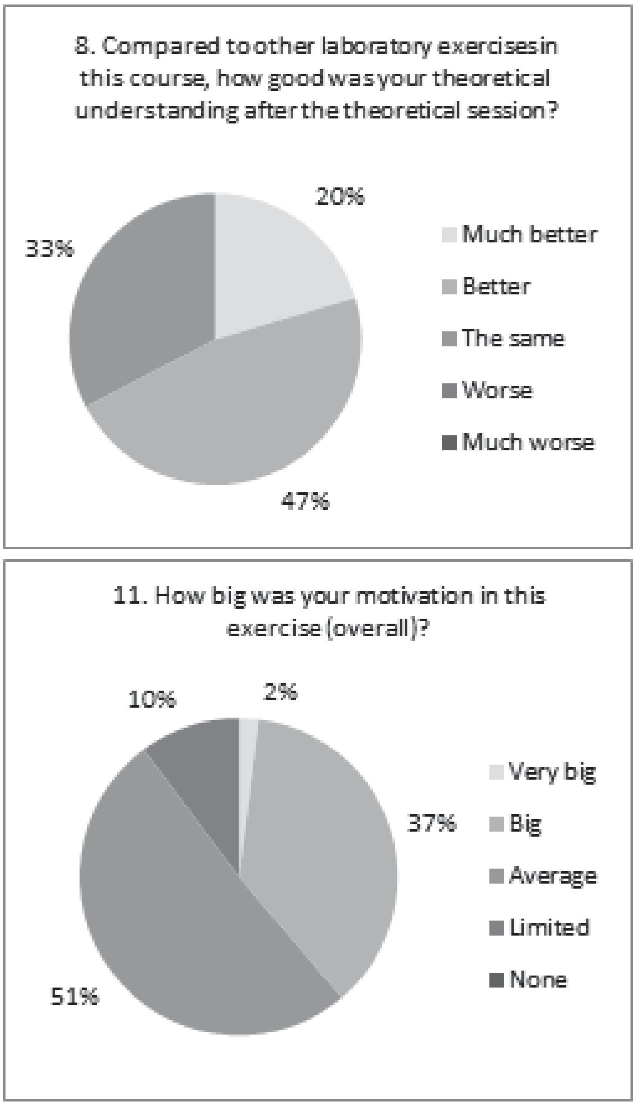


Fig. 5.1. Results from question 8 and question 11 – see Appendix.

is solely based on my judgment of the report schemes. In order to assess the effects properly, I should of course have given a short questionnaire to all students – not only to those having the extra theoretical session. And it would also have been valuable to assess the deeper theoretical understanding with a few questions, i.e. one month after the exercise. This would have given a better basis for the following discussion.

My hypothesis was that I could motivate the students and increase their learning outcome by giving them some tasks and information before going into the laboratory and conducting an exercise. I knew from my pre-project that the students actually appreciate to have pre-lab questions, and also want to be “forced” to think about, and discuss, the relevant theory. I wanted the students to understand some of the theoretical basis for how the experiment was designed (i.e. why is pH important?), and also to give them an understanding for the chosen methods, by guiding them with questions (i.e. why do we use ion exchange chromatography and not affinity chromatography or gel filtration chromatography?). More than 1/3 of the students felt motivated above average (see figure 5.1 and Appendix). My impression was that this did not result in more motivated students, when compared to those days without the theoretical session. This is based on the observation in the laboratory, where I think more motivation would result in more questions concerning the theory. But on the other hand, if the theory is clearly understood, then the lack of questions might not mean a lack of motivation.

Discussion

It is broadly accepted (according to the theory of constructivism) that in order to create new knowledge we need to build on what we already know (Biggs & Tang 2011*b*). Schwartz & Bransford (1998) talk about a “time for telling”, or as they also put it, “a “readiness” for being told something”. This point arises i.e. when we enter a learning situation with a lot of background knowledge, and a clear sense of the problems for which we seek solutions. However if we do not have any prior knowledge, new information will be memorized rather than being used to help the perception and thinking (Schwartz & Bransford 1998). From an experimental setup (see figure 5.2) Schwartz & Bransford (1998) conclude that providing students first with an opportunity to work actively with i.e. data, followed by a theoretical explanation as i.e. a lecture, provides the right setting for a deep understanding.

This implies then, that it might not be the most optimal setting to give the students a theoretical setting before working actively with the subject. On the other hand, by giving students pre-lab questions, we try to create some knowledge to be built upon. But this does not seem to create enough background knowledge to create the right setting for a “time for telling” (that is an optimal situation for deep learning) in the laboratory.

With reference to Schwartz & Bransford (1998), I think we should rather think of the importance of giving a theoretical session **after** the laboratory exercise, instead of before, as I have tried it in this setup. As I have also heard in a talk about teaching and learning, we need to make students

Three different groups of college students received different kinds of instruction about schema theory and memory and then completed a transfer task where they were asked to make detailed predictions about the results of a new memory study. Students in Group 1 read and summarized a text on the topic of schema theory and then listened to a lecture designed to help them organize their knowledge and learn with understanding. Group 2 did not read the text but, instead, actively compared simplified data sets from schema experiments on memory and then heard the same lecture as Group 1. Group 3 spent twice as much time as Group 2 working with the data sets but did not receive the organizing lecture. On the transfer test, students in Group 2 performed much better than those in Groups 1 and 3. Their work with the data sets set the stage for them to learn from the lecture. The lecture was necessary, as indicated by the poor performance of Group 3.

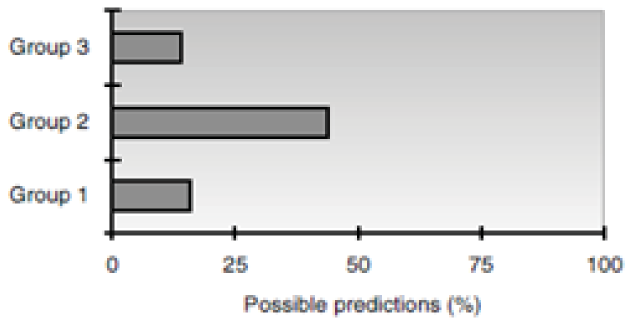


Fig. 5.2. Based on the results from experiment 3 in Schwartz & Bransford (1998), as presented in Bransford et al. (2000).

curious before they are ready to learn. In a laboratory setting, I think this could be done by focusing less on the theory in the introduction to each exercise, and maybe trying to make some of the steps during the practical exercise more open (according to what level the students are on, the level of openness should be adjusted) as also argued by (Tamir 1989). The important point is then, that after creating this momentum of "confusion" or curiosity, we need to provide a theoretical frame where the students can construct new knowledge by building on their experiences and observations in the laboratory. To some extend one can argue that this is already done in the form of the laboratory reports, but I don't think this is a sufficient tool to generate the deep learning from the exercise that we intend to give the students.

My focus has been how to increase the learning outcome from laboratory exercises, and aside from thinking in the line of the changes in the way the theory is presented to students (before or after a practical exercise), other points can also help to increase the learning outcome for the students. Reid & Shah (2007) points to the lack of clear aims in many laboratory manuals, where there is too much emphasis on the experiments to be performed and not enough emphasis on what the students should be gaining. This is an argument also highlighted by (Wood 1996), who furthermore writes that we should examine the motives for having students carrying out practical laboratory exercises. He also argues that in the early years of the university education, it would be preferable to separate some of the processes and skills we are trying to give the students, and as a progression during a course, finalise with an open-ended research project that demands a competently use of these skills (Wood 1996). Reid & Shah (2007) also underline the importance of pre-laboratory exercises as a mean to reduce the information overload on students (see figure 5.3), thereby also increasing their learning outcome. Reid & Shah (2007) also emphasise the importance of post-laboratory tasks, but has only few comments on what these could comprise, and not in the form of a lecture or similar way of giving a theoretical frame for the students.

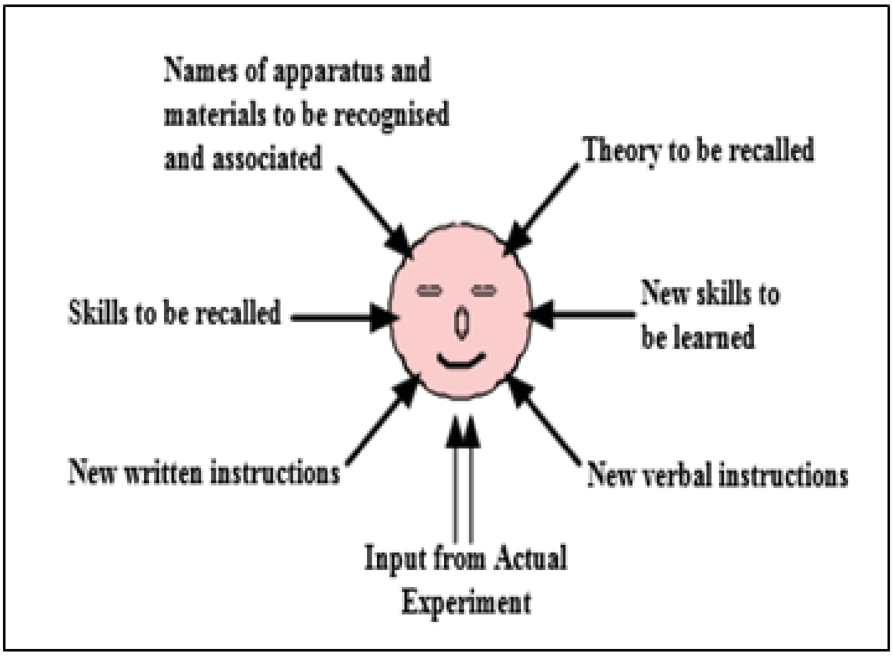


Fig. 5.3. Sources of information for students in undergraduate laboratories (Reid & Shah 2007).

Table 5.1. Laboratory practical work can develop skills and illustrate lecture (or textbook) content. The example chosen here is an enzyme assay (from (Wood 1996)).

Illustrates lectures	*Lab skills developed*
Enzyme catalysis demonstrated	Use of pipettte, spectrophotometer, understanding how assay is carried out
Enzymes are labile	Repeatability—only good if enzyme stored properly
Properties depend on conditions (pH, temperature)	Planning how to carry out assay (choosing appropriate conditions)
Form of kinetic curves	Manipulating data, deriving kinetic curves
Types of inhibition	Analysis of kinetic data

But what should the pre-lab questions then comprise of, in order to optimise the learning outcome? Reid and Shah (Reid & Shah 2007) writes that the aim of the pre-lab questions is to "prepare the mind for learning", by i.e. stimulating the students to think, encouraging them to recall or find facts, check the understanding of the experimental procedure, leading the students to thinking about the procedure and concepts etc.

With Schwartz & Bransford (1998) in mind, I would give more focus to the post-lab activities in the future when I have to plan the exercises in Biochemistry, as I didn't find the pre-lab questions and theory session useful enough for creating a deep learning of the matter intended. This does not mean that pre-lab questions are not justified, but should maybe be revised with a clear aim of the exercise in mind. This also applies to the laboratory manual itself, where the aims i.e. could be illustrated as shown in table 5.1. Furthermore, I would like to give more focus to the report schemes and the way they are evaluated (more formative than summative), maybe in another setup than the existing, where reports are returned with written comments and no oral feedback is given. But if the best "time for telling" is after the students have worked with the subject, then why not try to change the way we "teach" laboratory exercises, and focus on giving a theoretical frame after the exercise.

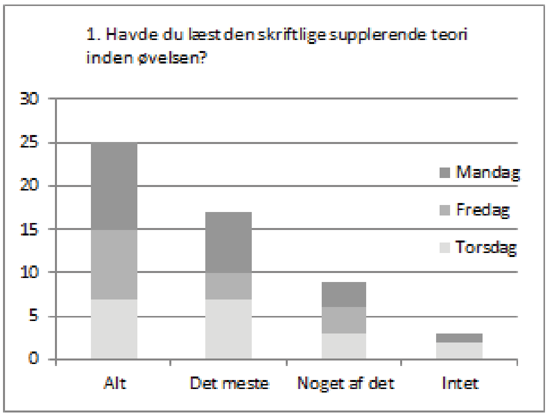
Concluding remarks

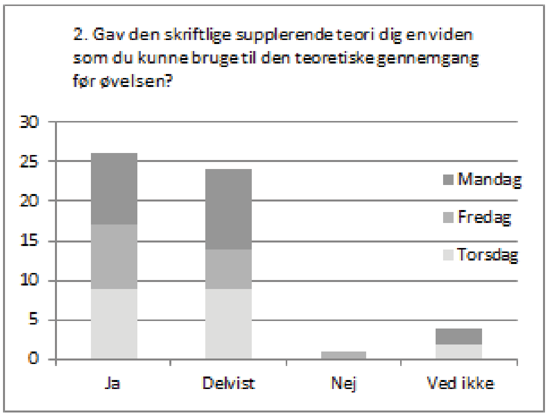
How we learn and how we as teachers can increase the learning outcome for the students in any given situation is in my opinion interesting to work with. In this project I have made an attempt to increase the learning outcome from a laboratory exercise, by having a theoretical session with the students before the practical laboratory exercise. The students responded positive to the initiative, though they also commented that the time spend was too long. I did not notice any clear positive effect with regard to motivation (more questions asked) or theoretical understanding (based on report schemes) after the theoretical session.

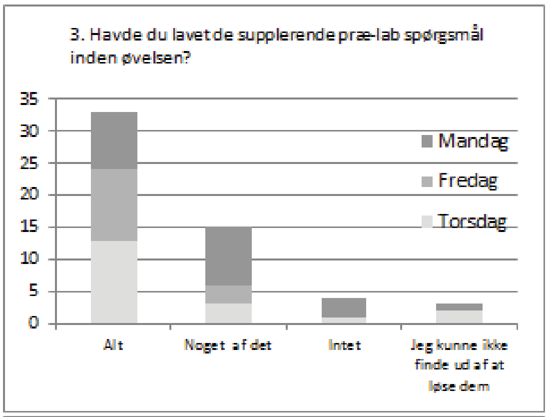
In the future, I would like to revise the laboratory manual, with clear aims in mind, as illustrated in table 1, where connection lines are drawn to the lectures, and practical skills are highlighted. Furthermore, I would like to see if it is possible to have less theory as introduction to the exercise, and maybe instead have the theory somewhere else, so we can make the students ready for the information before giving it to them ("time for telling"). I would also like to look into the possibilities for at post-lab session, either on the same day of the exercise, or the following week. In line with this, I also want to work with the report schemes and the way we evaluate the reports, which I would like to turn towards a formative evaluation rather than a summative. Both with respect to evaluation and post-lab session, with 220 students conducting the same exercise at 10 different 4 hour sessions, it is important to keep the practical aspects in mind, though they should not be an excuse for what is possible or not possible.

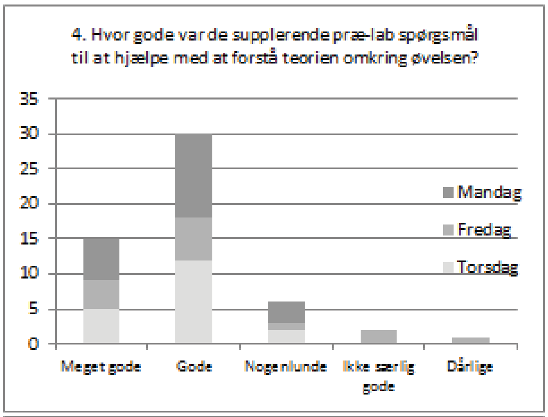
Appendix

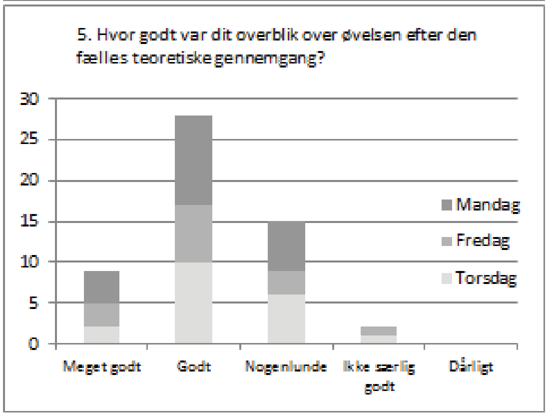
For all results below, the y-axis is the number of students.

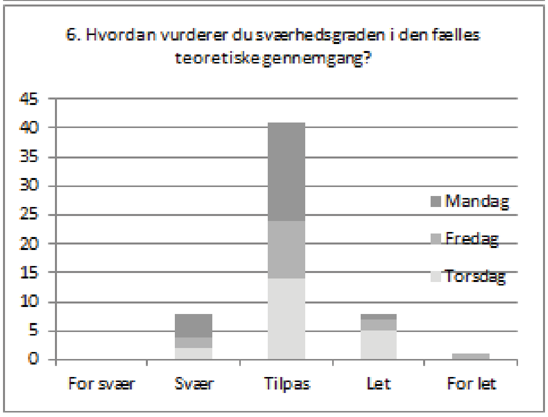


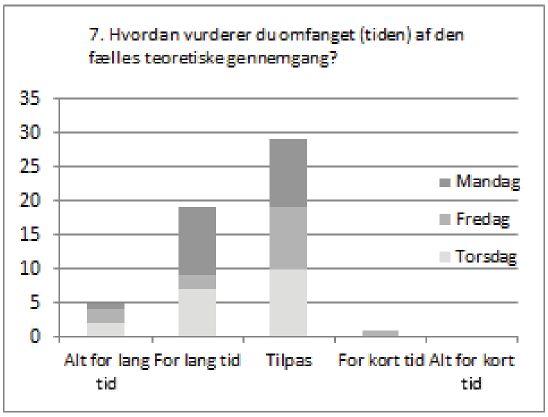


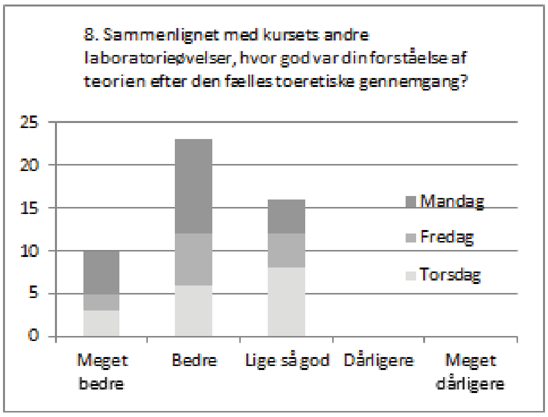









7. Hvordan vurderer du omfanget (tiden) af den fælles teoretiske gennemgang?
35
30
25
20
15
10
5
0
Mandag
Fredag
Torsdag
Alt for lang tid
For lang tid
Tilpas
For kort tid
Alt for kort tid


8. Sammenlignet med kursets andre laboratorieøvelser, hvor god var din forståelse af teorien efter den fælles toeretiske gennemgang?
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Meget bedre
Bedre
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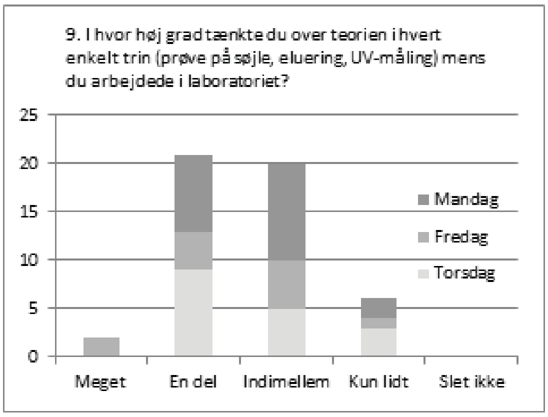
Dårligere
Meget dårligere


9. I hvor høj grad tænkte du over teorien i hvert enkelt trin (prøve på søjle, eluering, UV-måling) mens du arbejdede i laboratoriet?
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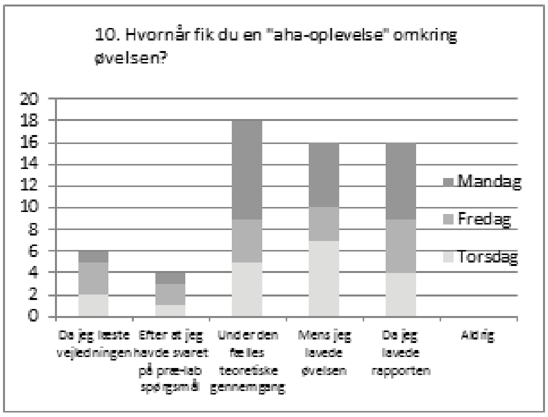
10. Hvornår fik du en "aha-oplevelse" omkring øvelsen?
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18
16
14
12
10
8
6
4
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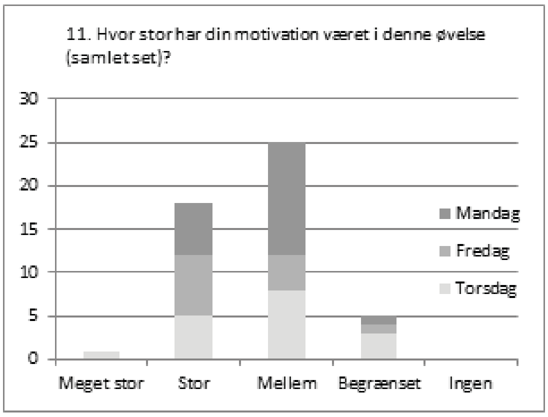
Mandag
Fredag
Torsdag
Da jeg læste vejledningen
Efter at jeg havde svaret på præ-lab spørgsmål
Under den fælles teoretiske gennemgang
Mens jeg lavede øvelsen
Da jeg lavede rapporten
Aldrig


11. Hvor stor har din motivation været i denne øvelse (samlet set)?
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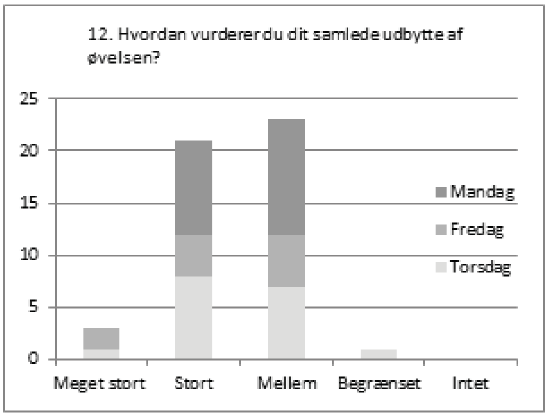
Meget stor
Stor
Mellem
Begrænset
Ingen


12. Hvordan vurderer du dit samlede udbytte af øvelsen?
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Meget stort
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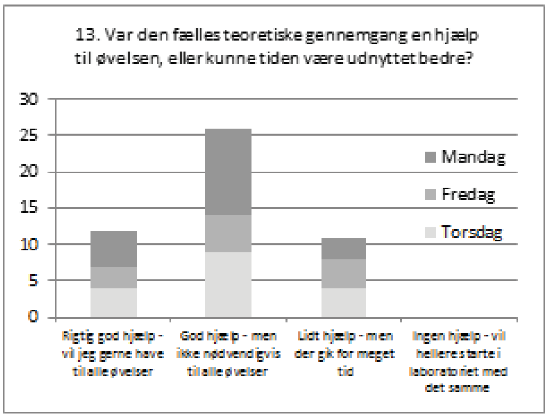

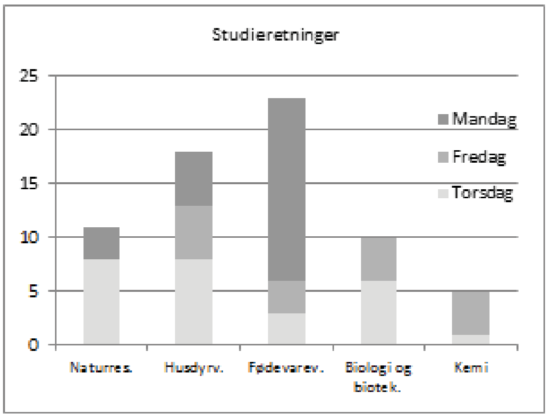

Comments:

Thursday: (19 out of 25 possible)

- I stedet for pre-lab-øvelser som i forvejen var en del af rapporten, var det måske bedre at erstatte opgaverne ét af stederne med andre opgaver.
- Måske unødvendigt, at det samme skulle tegnes i præ-lab, som i rapporten bagefter.
- Fælles teoretisk gennemgang kunne godt have indeholdt mere introduktion til selve udførelsen af forsøget - da det var svært, og øvelsesvejledningen var lidt forvirrende.
- Syntes det er en super idé med mere teoretisk stof i øvelsesvejledningen, men gennemgangen var lidt for lang, så det endte med at blive lidt kedeligt men det er et super initiativ :).

Friday: (14 out of 14 possible)

- Super gennemgang
- Synes det fungerer godt at snakke om tingene og få afklaring på det man ikke forstod i øvelsesvejledningen
- Den teoretiske tid skulle have været mere konkret, fortæl enkelt hvordan principperne skal forstås og lav en naturlig gennemgang af hvert trin. Jeg blev forvirret fordi det tog så lang tid.

Monday: (21 out of 24 possible)

- Den fælles teori var god men forsøgene skal afpasses hvis det bliver en regulær ting, da der næsten ikke var tid nok til forsøget.
- Det var godt med flow-sheet og fremvisning af udstyret. Ideen er rigtig god, men 45 minutter er meget lang tid og tiden kunne have været brugt

bedre, da jeg startede med de "samme problemer" jeg havde tænkt jeg ville støde på selvom teorien blev gennemgået.

- Fælles gennemgang var super godt, det tog bare lidt for lang tid, så vi havde svært ved at nå at udføre hele forsøget.
- Det var dejligt at mærke at du var så meget tilstede i laboratoriet. Det er lækkert at du gik rundt og fulgte op på hvor langt vi var, og om der var noget vi skulle have hjælp til.
- Jo mere fælles gennemgang og vejledning - jo bedre!

Fungi are characterized how...?

All contributions to this volume can be found at:

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