Improved integration of laboratories into the Bachelor's Programme in Physics

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Contents

Abstract

Laboratories are recognised as an important building block in physics education. The present study examines the laboratories in the courses of the Bachelor's Programme in Physics at Uppsala University, year 1 and 2, through interviews with students and teachers. The current style and organisation of the laboratories is analysed with regard to the integration in the respective courses and the programme. Topics and issues lifted from both student and teacher perspectives are discussed. Based on the obtained insights, a workshop for teachers is organised to stimulate discussion about these topics and two documents are presented to aid synchronisation between courses regarding the laboratories.

Table 1: Laboratory classes in the first two years of the Bachelor's Programme in Physics

Year	Period	Course with laboratory
1	1,2,3	Mechanics
1	3,4	Experimental Methods for Physics I
2	1,2	Electromagnetism
2	2	Waves and Optics
2	3	Mechanics 3
2	3,4	Quantum Physics
2	3,4	Thermodynamics

1 The role of laboratories in physics education

Laboratory work encompasses activities that give the students the opportunity to observe physical phenomena or processes, which has been recognised as an important part of the curriculum. This format can allow for high student autonomy in experiment choice, design, and data analysis [1]. The main goals include [2, 3]:

- Laboratories train students in developing hypotheses about physics processes or laws and then test these claims in experiments. Students learn to design experiments and perform own experimental work.
- Laboratories help to stimulate the students' interest in the topics and motivate for further studies.
- Laboratories provide an opportunity to attain practical instrumentation and data analysis skills.
- Laboratories offer possibilities for scientific dialogue in a stimulating learning environment.

Which form of instruction is most advantageous to reach the stated goals remains a controversial debate [1,4–6]. Structured, or guided instruction has traditionally been used in many physics laboratories. This means that the work follows a clearly structured manual on a predetermined topic. Especially for learners with little prior knowledge, this approach can be helpful to avoid high cognitive load and possible frustration that occurs without guidance [4]. Open-ended instruction, which leaves more experimental freedom for the students, has been promoted to show a positive effect on the students' confidence regarding experimental work [1] and can facilitate a higher degree of student autonomy [7].

2 Aim and scope

The project aims to systematically evaluate and improve the laboratory course components in the Bachelor's Programme in Physics and the Upper Secondary School Teacher Education Programme - Physics and Mathematics. The programmes include laboratory classes at all levels throughout the programme, as visualised in Table 1.

The projects encompasses the following aims:

- Assess the role of laboratory courses in natural science education, including ethical considerations and contributions to the social development of the students
- Systematically map which laboratory courses are carried out in the Bachelor's Programme in Physics including their goals and structure. This list is then to be distributed to both teachers and students.

- Identify relations and advances, for example concerning the experimental techniques or the analysis of data, between laboratories in different courses
- Develop a course or workshop on the pedagogical aspects of laboratory courses as outlined in this report.

An overview on the current research in the field is carried out by both a literature survey and discussions with the division for physics education. From this background, criteria, which are analysed for each laboratory are selected. The laboratories are analysed with the help of interviews with both laboratory teachers and students from recent laboratory courses. From the interviews, representing the current status, suggestions for development are selected. The selection of courses is limited to the first two years of the Bachelor's Programme in Physics, as this represents the phase where all students take the same courses.

3 Methods

Both the student and the teacher perspective on the different laboratories summarised in Table 1 and their course integration was evaluated from interviews. The number of teachers and students interviewed from each laboratory is listed in Table 2. The participants received a survey with questions before the interview, which was used as a guide to go through the topics. The multiple-choice and short text answers were taken as a basis for the interview. The questions were selected to reflect the topics discussed in the report: Organisation and course integration, and instructions. As an example, the questionnaire for the laboratory teachers is attached to this report.

Table 2: Number of interviews for the individual courses

Laboratory	**Teachers**	**Students**
Mechanics	2	3
Experimental Methods for Physics I	3	3
Electromagnetism	1	3
Waves and Optics	1	3
Mechanics 3	1	3
Quantum Physics	1	3
Thermodynamics	2[1]	2

Qualitative interviews with open questions were chosen to get descriptive answers about the participants' experiences. This method is suitable if not all aspects of interest are known beforehand, but arise from the descriptions given by the participants about their experiences [8, 9]. As this involves the use personal information, confidentiality is important to consider [8, 10]:

1. The participants have to be informed about the aims of the study prior to their participation.
2. They must be informed that their contribution is voluntary and they might terminate their involvement at any time.
3. All personal data must be handled with confidentiality and
4. the data may only be used for the stated purpose.

[1]The authors of this report are also the two laboratory teachers.

Participants are made aware of these points in the beginning of an interview. In the report, names and personal information will not be mentioned to ensure the participants' anonymity. Only the authors and the participating student interviewers of this study will have access to the original interviews including personal data. For both the interviews with teachers and students, notes were taken during the interviews for later analysis. The teacher interviews were additionally recorded to allow a more detailed evaluation later on. The notes were used to create summaries of the participants' impressions. From these, common and key observations were condensed in the present report to give an overview of the perceptions concerning individual courses, but moreover the laboratory classes as a whole.

4 Students' observations

Organisational aspects

The number of teachers present in the laboratory was mostly perceived as sufficient, even if occasionally some waiting time occurred, and the students described the teachers as ready to help and answer questions or even stay longer if needed. Enthusiastic teachers were appreciated to make the tasks more lively. Only very few students expressed that too much guidance during the laboratory was hampering own exploration. In most cases the teachers were perceived as knowledgeable about the subject, the equipment, and the tasks. In a few cases the students perceived some lack of preparation on the teachers' side. In the course Experimental Methods the laboratory project was conducted during several weeks and the students had to book time with their assigned supervisor, which overall worked out well. Most supplied equipment was described as generally working well. Problems with the equipment could take the focus away from the topics to investigate or time for data analysis. Some students noted that it could be difficult to understand how the equipment functioned. In the laboratories in Electromagnetism it occurred that there was not enough equipment available for all groups.

For the first laboratory of the programme, in Mechanics, previous general knowledge was perceived as helpful. In the following laboratories, the gathered general experience was noted as helpful, and could be applied for more efficient preparation and time management. Programming experience, uncertainty calculations, team working skills, and experience with report writing was also beneficial for the laboratories later in the programme. However, the benefit from previous laboratories within the same course was observed differently by the students. All laboratories were described to feel generally relevant and added intuition to the theoretical concepts for the course. In many cases, the laboratories were described as disconnected from other course components. The teachers from different parts (lectures, lessons, laboratories) did not seem to communicate or be informed about the other course components. More relation and synchronisation between these different parts, possibly also motivated in the instructions, would have been appreciated.

Time was generally sufficient, but for most courses not available at excess to explore further than required by the instructions. Additional open questions, or less repetition on the step-by-step instructions and in turn time to explore, would have helped to explore more freely and deepen the understanding instead of stress evolving around getting an exact task done. When there was extra time to conduct additional own experiments, this was seen as a compliment to the laboratory. In courses with more open-ended laboratories, Thermodynamics and Experimental Methods, the own time deposition worked well.

The examination forms of the respective subjects were recognised as fitting. Report writing and oral exams were described as good exercises for later exams. In cases where the laboratory was examined by a written report, this was generally considered a good choice. The opinions about oral examinations or presentations different between the students, partly due to unclear requirements, partly due to different balance between discussion and examination. The poster session in Experimental Methods was welcomed as an inspiring format.

Instructions and preparation

The laboratory instructions were mostly clear to the students. However, there was often missing or contradicting information due to outdated manuals or not updated submission deadlines. Instructions for more guided laboratories were appreciated as clear, but at the same time criticised as inauthentic. The introduction of physics concepts was perceived as helpful, but sometimes presented in a very shorthanded summary of the underlying theory. Instructions for open-ended laboratories leave experimental freedom but in the case of Experimental Methods were clear about the organisational aspects. In Thermodynamics, more guidance on how to prepare the experiments would have been helpful.

All of the more guided laboratories employed preparatory questions or quizzes, while the open-ended laboratories required a project plan or proposal. The preparatory questions were appreciated when they felt relevant for the laboratory work. For Thermodynamics, more feedback on the proposal would have been needed to adjust the planning to the experimental possibilities in some cases.

5 Teachers' observations

Organisational aspects

The number of laboratory sessions varied from 8 (Mechanics, Electromagnetism) to 1-3 (Experimental Methods, Waves and Optics, Mechanics 3, Quantum Physics, Thermodynamics). Thus, the first laboratories in the programme typically encompass more sessions. The course in Experimental Methods follows a different approach with open-ended project work and does therefore not encompass a determined number of sessions. Concerning the allocated time, most laboratories had sufficient scheduled time for most students to finish their work. However, in most courses the laboratory teachers offered some extra time for the few students who needed to complete their experiments. The first year courses required high-school experience, while in the later courses, general laboratory experience from the previous courses was expected. The majority of laboratory teachers was only vaguely familiar with the students' prior laboratory experience. However, the teachers did not consider their lack of knowledge as a disadvantage for their teaching. The equipment of the individual laboratories was described as mostly functional as expected. In some cases, technical problems with some equipment took focus off the actual task and physics concepts, furthermore, some of the equipment is perceived as getting worn or outdated.

One focus of the interviews was the integration of the laboratory into the respective course and their connection to the other course elements, such as lectures and exercise sessions. Almost all interviewed laboratory teachers described the other course elements as disconnected to some degree. Often the role and integration of the laboratory is shortly discussed at a course start meeting, but the actual implementation is run more or less autonomously by the laboratory teachers. In most cases it is up to the individual laboratory teacher's initiative to gather additional information and synchronise the laboratory with the other course components. Many of the teachers expressed that a more firm integration and harmonisation could be helpful, whereas in some cases the impression was that the present detachment is both sufficient and time efficient. As an exception, the project work of the Experimental Methods course stood out and was described as an application of the skills taught in the course and therefore fully integrated. Here, also the teachers that did not participate in all activities knew how the interconnection was planned.

All laboratories require a certain level of understanding of the underlying physics or methods taught in the course for the students to pass. In some cases these learning goals are also specified in the instructions. If these goals were reached is examined in different forms. All laboratories except Quantum Physics and Thermodynamics require at least one full report for one of the sessions or experiments. In addition, protocols are used to shortly discuss the results and learning goals. Other elements and examination forms include peer-review feedback via DiaNa forms [11], oral interviews, and poster sessions.

Instructions and preparation

The successful implementation of a laboratory requires preparation from both teacher and student side. Instructions are essential for this and can vary in format and detail. None of the laboratory teachers received formal instructions to laboratory teaching. In most cases, previous or current student manuals as well as help from more experienced fellow teachers was available for new laboratory teachers to familiarise themselves with the tasks. How prepared the teachers are, therefore depends largely on their own initiative and access to informal help. In some cases, this was experienced as a self-evident part of the preparation and handled within the teacher group without need for further formalisation. In other cases, this could lead to overtaxing of new teachers, for example if there are additionally language barriers for non-native Swedish speakers.

The teachers evaluated the student instructions as mostly clear in all cases. Most courses employed guided, step-by-step instructions. The course in Experimental Methods is based on open-ended project work, therefore the instructions mostly concern organisational details but no instructions on the individual projects. All laboratories included preparatory questions, which were examined in different forms. These tasks seemed to activate the students even if they were not individually examined. No students were excluded from the laboratories on the basis of their answers to the preparatory questions, instead the teachers used these occasions to clarify concepts. For the open-ended project-based laboratories (Experimental Methods and Thermodynamics), the preparatory task consisted in a project plan or proposal.

6 Discussion

Connection between the different course elements

In most cases, both teachers and students perceived the laboratories as disconnected from the other course parts. This hinders the achievement of the goal that laboratories should stimulate the interest in the course content. A possible countermeasure is instructions for the laboratory teachers telling what the students should have learned in the lectures prior to the laboratories. These instructions should include references to lectures and/or course literature, thus linking the theory part to the rest of the course. Obviously, these instructions must be well synchronised with the current course instance. Another way to improve the interaction between the laboratories and the other course components is to use data or examples from laboratory measurements in the problem solving sessions. As an example for this synchronisation we sketched a possible implementation for the course in Thermodynamics. The draft illustrates the links between lecture content and the laboratory experiments on the one side and between the laboratory results and the exercise sessions on the other. It is included in the attachments.

The integration of the laboratories in the course can also be improved by a tight and regular dialogue between all teachers involved in the course. In many cases, there is a start-up meeting which can serve as initiation for further dialogue. This is best taken care of by the course responsible teacher. The synchronisation between the laboratories, the lectures and the problem solving sessions could result in changes in all three components to best suit the expected learning outcomes. This study focused on laboratories, which might have guided the students to answer that they perceived the laboratories as decoupled from the rest of the course. The laboratory teachers, naturally, took the viewpoint that the course is not adapted to the laboratories. Which of these perspectives is closer to the "truth" (as stated in the expected learning outcomes) probably varies from course to course, but should be discussed openly. A starting point for these discussions will be provided by the teachers' workshop realised though this project, see the attached preliminary programme.

Instruction of new laboratory teachers

In several interviews, students commented on ill-prepared laboratory teachers. At the same time, most of laboratory teachers reported that their preparation depended almost entirely on their own initiative. The department of physics and astronomy offers yearly introductions for laboratory teachers, but these are general, not course specific, and the attendance is voluntary. The fact that there are no established routines for the introduction of new laboratory teachers to a specific course in combination with the relatively high fluctuation among the laboratory teachers (mainly PhD students) leads to the risk of losing good practice and knowledge and results in varying competence and teaching quality over time. The introduction of new laboratory teachers should fall under the responsibility of the course responsible teacher. Ways how this can be amended will be discussed at the planned workshop.

Laboratory styles and instructions

Most laboratories presented here are taught in a guided style with clear written instructions. In almost all cases, the students had to do preparatory tasks in order to achieve some level of preparation. The guided style makes the laboratories better predictable and helps preventing a cognitive overload [4], which is a relevant aspect, especially in early courses. On the other hand, open-ended laboratories are appreciated as authentic scientific practice and aid in the development of methodological skills [1, 7], which was also reflected in the student interviews. Open-ended instructions require scaffolding to avoid cognitive overload [12]. The students' answers indicate that this is well implemented in the course Experimental Methods, where the instructions were perceived as clear even though the experiment was open-ended. Even the course Mechanics 3 encompasses one open-ended exploratory style laboratory, which was well-received by the students. The third open-ended laboratory, in Thermodynamics, received more criticism, mainly for a lack of sufficient scaffolding. For future instances of the course, the teachers will improve on that point.

In most cases, the students considered the preparatory questions as not very relevant for the actual laboratory. A better alignment of the laboratory instructions, the preparatory questions or tasks, the laboratory itself and its examination with the expected learning outcomes would be desirable. Also, this alignment should be communicated more clearly to the students.

Examination forms

In most courses including laboratories, one of them is examined with a written report, while the other laboratories in the course use other examination forms. This combination was generally appreciated by the students. Within each course, it would be desirable to stimulate a dialogue between the teachers about the form of the laboratory instructions, the laboratory style, the way the students are examined and how this relates to the expected learning outcomes from the laboratory. We will discuss examples for this constructive linking during the above mentioned workshop.

Concerning written reports, it was mentioned in the student interviews that clearer instructions on how to write them and what kind of feedback to expect, would be of value. As a part of the present project, a guidance document on laboratory reports has been developed on the basis of the manual provided in the course in Mechanics and the general instructions by the physics department. This document will be discussed with the laboratory teachers and can then be used to synchronise the style and expectations concerning reports. We will inform the course responsible teachers about this document and ask them to upload it on their respective course pages, so that all students always have access to it.

Those laboratories after which the students don't write reports offer a variety of oral examination forms, ranging from oral presentations and poster sessions to protocol discussions and question sessions. Seen over the whole programme, these oral examinations should have a balance between the checking of results and an inquiry about physics understanding as well as a discussion about experimental uncertainties and errors. For each individual laboratory, this should again relate back to the intended learning outcomes. The character of the discussion can vary between an examination with the goal to pass the students and a reflective discussion with the idea to stimulate further learning. Both the students and some of the laboratory teachers expressed the opinion that the second style would be preferable. This would, however, require more teaching personnel during the laboratories, at least during the discussion phase. It is worth noting that some students express that they experience guided laboratories as inauthentic. To what extend this should be reflected in the layout of the laboratories is another subject that will be discussed at the workshop.

Progression

The students acknowledged a gain of general laboratory skills in the course of the programme. Competences mentioned included programming experience, uncertainty calculations, team working skills, and experience with report writing. Due to their limited insight in the students' achievements in other courses, the laboratory teachers were not able to judge the students' progression beyond their own course. As a first step, the laboratory overview (see below) will help to inform the teachers about the students' expected progression concerning laboratory work.

7 Development of a teachers' workshop

All teachers involved in the Bachelor's Programme in Physics (year 1 and 2) will be invited to a workshop which will take place in autumn 2022. The preliminary programme includes the following points:

- Welcome and introduction
- Short summary of our study and main findings
- Ideas, exchange and discussion in groups
  - Introduction and instruction of new laboratory teachers. Best practise and harmonisation
  - Constructive linking between laboratory instructions, style, examination according to the expected learning outcomes for the laboratory
  - Constructive linking between the course lectures, the problem solving sessions, the laboratories, the examination according to the expected learning outcomes for the course
  - Progression and integration of the laboratories in the Bachelor's Programme
  - Guided and open-ended laboratories. Choice, implementation, pitfalls and possibilities
- Summary and discussion on implementation of changes

- Opportunity for exchange and mingle among teachers

Ethical aspects in physics in general and specially of laboratory work are introduced and discussed in the course Experimental Methods in Physics I. The question how this topic can be implemented in other courses will be discussed at a separate teacher day, which the programme plans for the autumn.

8 Conclusions and outlook

We interviewed laboratory teachers and students about their teaching and learning experiences during the laboratories in the Bachelor's Programme in Physics. Overall, both students and teachers expressed a reasonably high level of satisfaction with their laboratories. From the interviews, we evaluated issues raised from both sides. This concerned mainly the integration of the laboratories in the respective courses, the continuity of teacher engagement, the instruction style and material, and the examination forms. On the basis of the presented results and discussion, areas for exchange and improvement are proposed for discussion at a teachers' workshop. The workshop will be carried out during autumn 2022 and a preliminary programme is included in this report. A survey over all laboratories during the first two years of the Bachelor's programme and guidelines for report writing have been written and will be distributed to the students and teachers. The Bachelor's programme's regular student feedback meetings allow for a detailed follow-up of the effects of the measures that might be decided upon during the workshop.

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9 Attachments

Questionnaire for laboratory teachers

Laboratory work within the Bachelor's Programme in Physics

You get this form because you agreed to take part in an inquiry about the labs within the Bachelor’s Programme in Physics at Uppsala University. The questions are quite general, but you should answer them only for the specific course in which you have been lab assistant and that was indicated when you were asked for an interview. The idea is that the form should be filled in before the interview, so that all material has been written down and summarized, and the interview can focus on in-depth questions.

After the interview and a compilation of the material we will make your answers anonymous. It is, however, relevant to know which laboratory your answers deal with.

*Obligatorisk

1. How many laboratories were part of the course, how many lab assistants were you and for how many students? *

2. Did you get clear instructions what the students were supposed to do in the lab and what they should learn? Please choose.

   Markera alla som gäller.

   - ☐ Yes, I got clear instructions
   - ☐ I got some instructions, but they were not clear
   - ☐ I did not get any instructions
   - ☐ Other

3. Did the students get clear instructions what they were supposed to do and what results they were expected to obtain? Please choose.

   Markera alla som gäller.

   - ☐ Yes, they got clear instructions
   - ☐ They got instructions, but they were not clear
   - ☐ No, the students did not get any instructions
   - ☐ Other

4. Did the students have to hand in preparatory questions before the lab? Please choose.

Markera alla som gäller.

- ☐ Written hand-in exercises, to be handed in before the laboratory
- ☐ Study questions, oral interview before the laboratory
- ☐ No preparatory tasks
- ☐ Other

5. What physics insights or results were required for the students to pass the laboratory?

6. Do you know which laboratories the students had done earlier, i.e. which lab competences they should have?

Fortsätt till fråga 7

Laborationer vid kandidatprogrammet i fysik

7. How would you describe the laboratory's layout? Please choose.

Markera alla som gäller.

- ☐ Guided activities, i.e. detailed instructions
- ☐ Inquiry style, i.e. open ended approach
- ☐ Other

8. Did the lab equipment work? Could the students focus on the physics or were they hindered by technical problems?

9. How was the laboratory examined? Please choose.

   Markera alla som gäller.

   - [ ] Lab report
   - [ ] Oral presentation
   - [ ] Protocol with measuring results
   - [ ] Other

10. Do you know how the laboratory relates to the rest of the course? (E.g. as an illustration of the actual course content, as a complement, free-standing...)

   Markera alla som gäller.

   - [ ] Yes
   - [ ] No
   - [ ] Other

11. Was the time allocated for the laboratory sufficient for most of the students? Please choose.

   Markera alla som gäller.

   - [ ] Sufficient time for all students
   - [ ] Sufficient time for most students
   - [ ] Insufficient time
   - [ ] Other

12. Did you experience that (most of) the students were prepared for the laboratory? If not, what was missing, physics or “measuring techniques”? Please choose.

Markera alla som gäller.

- [ ] Most of the students were prepared
- [ ] Many students were lacking the physics background
- [ ] Many students were lacking knowledge about instrumentation
- [ ] Other

13. Did you experience that the students were satisfied with the laboratory? Please choose.

Markera alla som gäller.

- [ ] Yes, all students seemed satisfied
- [ ] Yes, most students seemed satisfied
- [ ] Well, a lot of students seemed unsatisfied
- [ ] Other

Laboratory overview

Mekanik KF

(1) Dimensionsanalys	open-ended	Mätprotokoll
(2) Kinematik	guided	Mätprotokoll
(3) Krafter och Newtons lager	guided	Mätprotokoll
(4) Stötförsök med rull- och glidbana	guided	Labbrapport
		Muntlig examination (1) – (4)
(5) Roterande referenssystem	guided	Mätprotokoll
(6) Rotationsrörelse	guided	Labbrapport
(7) Ballistisk pendel	guided	Mätprotokoll
(8) Harmonisk svängning	guided	Mätprotokoll
		Muntlig examination (5) – (8)

Experimentell metodik för fysik I

Olika experiment eller mätningar	open-ended	Poster och labbrapport

Elektromagnetism

Kopplingsövningar med lampor och lysdioder	guided	Mätprotokoll
Elektrisk mätteknik och mätinstrument	guided	Mätprotokoll
Kondensatorförsök	guided	Mätprotokoll
Magnetiska fält	guided	Labbrapport
Hysteresis	guided	Mätprotokoll
Induktion	guided	Mätprotokoll
Växelström I och II	guided	Mätprotokoll

Mekanik III

Kopplade svängningar	guided	Labbrapport
Gyroskop	open-ended	Mätprotokoll

Termodynamik

Olika experiment	open-ended	Muntlig presentation

Kvantfysik

Optisk spektroskopi av väte	guided	Mätprotokoll
Fotoelektriska effekten	guided	Mätprotokoll
Röntgenspektroskopi	guided	Muntlig presentation

Rapportskrivning KF

Matthias Weiszflog, Inga K. Goetz och många andra under ett antal år

25 maj 2022

Sammanfattning

Det här dokumentet är ett försök att sammanställa några riktlinjer för hur labbrapporter bör se ut. Målgruppen är studenter på kandidatprogrammet i fysik och på ämneslärarprogrammet för fysik och matematik samt deras labbhandledare.

Texten är en kombination av instruktionerna för laborationerna på kursen Mekanik KF och institutionens instruktioner för fullständiga labbrapporter. Ett stort tack till alla som har skrivit och finslipat dessa dokument.

1 Syfte & mål

Syftet med rapportskrivning på kandidatprogrammet i fysik är att du ska få träna på att sammanfatta och kommunicera laborativt arbete i skrift[1]. Vetenskapliga rapporter antar ofta en speciell form vars detaljer kan variera men som i princip följer det mönster som presenteras nedan, genom arbetet med rapporter i programmets olika kurser kommer du att få feedback på hur väl du lyckas följa den givna mallen och även på ditt språk[2].

Målen med rapportskrivningen är att du ska känna igen delarna i en vetenskaplig rapport och att du ska kunna använda en given mall för att sammanfatta dina resultat på ett sådant sätt att en läsare varken behöver laborationsinstruktionen eller dig närvarande för att förstå vad ni gjort, hur ni gjorde, hur ni analyserade vad ni gjort och vad ni kom fram till.

2 Struktur av en vetenskaplig text

Grundregeln för en fullständig rapport är att den ska kunna läsas fristående utan att man vet något om laborationen[3]. Efter att ha läst din text bör läsaren förstå vad ni gjorde, varför ni gjorde det och

[1] I denna text används begreppen "rapport" och "labbrapport" synonymt.

[2] Språkverkstaden erbjuder hjälp med språk oavsett om du behöver hjälp med grunderna eller om du vill slipa på något. Se `https://www.sprakverkstaden.uu.se/boka/`

[3] Till skillnad från fullständiga labbrapporter finns även korta labbrapporter som inte behöver kunna läsas fristående. Den här texten handlar dock endast om fullständiga rapporter.

vad ni kom fram till, samt hur ni kom fram till det. En god tumregel är att läsaren, givet din text och (nu när vi talar om rapporter som rör laborativt arbete) samma utrustning skall kunna upprepa försöket du beskriver och komma fram till samma resultat genom att analysera mätresultaten på sättet du beskrivit[4]. Tänk också på att "vi" i en vetenskaplig text är författarna och läsarna tillsammans.

Institutionen för fysik och astronomi har sammanställt instruktioner för fullständiga rapporter[5]. Enligt dessa instruktioner ska en fullständig rapport, förutom en *titel* och en *sammanfattning* (ibland kallat *"abstract"*) även innehålla en *inledning*, ett eller några *mål* för laborationen, en sammanfattning av bakomliggande *teori*, en beskrivning av *metod* eller *experiment*, en redovisning av alla *resultat*, en *diskussion* av dessa, några *slutsatser* samt alla *referenser* som du har använt.

Fritt tillgänglig mjukvara som kan underlätta rapportskrivandet är LaTeX[6] som introduceras i kandidatprogrammets introduktionskurs. Incscape[7] och Gimp[8] är grafikprogram, det förra lämpar sig för skisser medan det senare är bra för bildhantering. Båda programmen kan producera grafik i .eps-format som fungerar bra tillsammans med LaTeX. Även Python[9] och matplotlib[10] kan producera .eps-figurer.

Nedan följer korta beskrivningar vad rapportens enskilda avsnitt ska innehålla:

Titel och sammanfattning

Titeln på rapporten skall vara kort och kärnfull. Behövs det för klarhet kan en undertitel läggas till. På rapportens framsida skall det också framgå vilka som skrivit rapporten, ni bör både för och efternamn. (I vetenskapliga texter är det annars vanligt att endast ange initial(er) och efternamn.) Ange också vilken kurs och vilka laborationsassistenterna var och rapportens datum.

Sammanfattningen (abstract) skall vara kort och beskriva vad rapporten handlar om och vilket resultat som presenteras. Det är bra att runda av med hur slutsatsen som dras förhåller sig till liknande experiment/analyser. Titel, författarnamn och sammanfattningen står ofta på rapportens första sida. Om resten av rapporten brinner upp i skrivaren (eller om någon inte orkar läsa mera) vet läsaren efter att ha sett framsidan vilken kurs, vilka som skrev rapporten, vad som gjordes och med vilket resultat.

Inledning

Här svarar du på frågan "varför?"[11]. Försök göra läsaren intresserad, ge sammanhang och ev. perspektiv på fysiken som skall undersökas. Undvik att ge triviala sammanhang som "I kursen ... gör vi den här laborationen för att undersöka ...". Inkludera gärna en enkel figur om det underlättar förståelsen för introduktionen.

[4] Medan du skriver kan du själv tänka efter "vad skulle jag behöva veta för att upprepa det jag skriver om?"
[5] Dokumentet finns på medarbetarportalen och är därmed tillgängligt endast för anställda.
[6] Se https://www.latex-project.org/
[7] Se https://inkscape.org/
[8] Se https://inkscape.org/
[9] Se https://www.python.org/
[10] Se https://matplotlib.org/
[11] Undvik gärna motiveringar som "för att vi måste".

Mål

Här beskrivs målsättningen med arbetet. Vad hoppas man åstadkomma? Vilken kunskap kommer man att samla in? Testar arbetet en teknik? Varför görs undersökningen?

Teori

I detta avsnitt ska den teoretiska bakgrunden för arbetet presenteras. Man ska beskriva den teoretiska formalism som behövs för att läsaren ska förstå resultaten. Formler, modeller, teorem, o.s.v. bör presenteras, förklaras i detalj och sättas i relation till det utförda arbetet. Formler ska numreras så att de kan refereras till i senare avsnitt. Den teoretiska bakgrunden ska inte vara en uppräkning av formler och begrepp, utan ett väl utarbetat avsnitt där läsaren får tillräcklig information för att förstå den formalism som används i teorin som beskriver de fenomen som studeras. Det är viktigt att komma ihåg att teoriavsnittet inte behöver innehålla den kompletta vetenskapliga bakgrunden till det aktuella arbetet, men all information som är helt nödvändig och relevant för förståelsen måste tas upp uttryckligen, och resten ska kunna hittas i lämpliga referenser som också anges.

Metod/Experiment

Laboratorieuppställningen beskrivs detaljerat, liksom tillvägagångssätten för att samla in de data som redovisas. Hur fungerar uppställningen? Vilka fysikaliska processer är inblandade? Hur är eventuella koordinater för olika mätpunkter definierade? Lika viktiga som själva datamängden är också osäkerheter och fel. Alla experimentuppställningar har sina felkällor och begränsningar, och det är mycket viktigt att beskriva dem och identifiera vilka som är relevanta och varför. Att kunna återskapa andra forskares arbete är avgörande för det vetenskapliga arbetssättet. Därför måste alla vetenskapliga rapporter/artiklar ha en tydlig förklaring av tillvägagångssätt (metodologi). Hur mättes respektive storhet? Vilka parametrar användes? Använde man någon approximation? Det är väsentligt att besvara dessa frågor när man beskriver hur man fick fram en datamängd.

Resultat

Här måste egna data presenteras på ett klart och tydligt sätt, med förklaringar till var data kommer ifrån och eventuella felkällor. Tabeller måste identifieras med nummer, tydliga rubriker och beskrivande tabelltext. När man hänvisar till tabellen i texten måste man referera till tabellnumret. Eventuella diagram ska också vara klara och tydliga med läsliga etiketter och förklaringar till vad varje kurva eller datamängd visar. De ska ha en figurtext som kort förklarar innehållet och vara numrerade så man kan referera till dem i den omgivande texten. Alla axlar måste ha både storhet och enhet angivna. En allmän konvention är att visa uppmätta data med symboler (*, +, etc.) medan anpassade eller beräknade värden ritas som linjer (heldragna, streckade, prickade, etc.). Om man anpassar en ekvation till data så ska ekvationen anges i texten, eventuellt även i figuren, och anpassningsparametrarna ska då anges med sina osäkerheter. Mätosäkerheter bör även inkluderas i diagrammet, och om de är för små för att vara synliga måste detta nämnas i figurtexten (t.ex. "osäkerheterna är mindre än symbolerna i diagrammet").

Diskussion

I detta avsnitt ska resultaten diskuteras och analyseras med hjälp av den tidigare presenterade teoretiska bakgrunden. Denna analys måste göras kritiskt: stämmer våra resultat överens med teoretiska förutsägelser? Om detta är fallet så måste man argumentera för varför man ser en överensstämmelse. Om resultaten inte uppfyller förväntningarna måste man återigen motivera detta. Om de förväntade resultaten är väl etablerade måste man förmodligen undersöka sina egna resultat och möjliga felkällor mycket noga, men man måste alltid komma ihåg att det inte finns några absoluta sanningar i naturvetenskapen. Om det finns tillräckliga belägg för att en viss förutsägelse är felaktig så måste teorin ändras. Det viktiga är att kommentera sina resultats giltighet. Undvik förutfattade meningar eller subjektiva kommentarer, eftersom det inte spelar någon roll för resultatets giltighet vem som utfört mätningen eller om den upplevdes som rolig att göra.

Om resultatet är specifika parametrar som kan jämföras med teoretiska och/eller tabellerade värden måste relativa felet mellan dem beräknas. För varje mätvärde bör också absoluta osäkerheten presenteras och det ska diskuteras om den är tillräckligt stor för att påverka slutsatserna.

Slutsatser

Här ska det viktigaste från laborationen sammanfattas och presenteras och en slutsats ska ges. Analysen sammanfattas kort för att göra de viktigaste upptäckterna tydliga för läsaren. Läsaren ska kunna läsa enbart avsnitten *Introduktion* och *Slutsatser* och få en översiktlig bild av vad som åstadkommits.

Referenser

Här anges alla relevanta referenser (informationskällor) för rapporten.

3 Enkla åtgärder som gör stor skillnad

Några allmänna punkter

- Tänk på vem du skriver för. I fallet med labbrapporter bör du anta att du skriver för en student som skall utföra laborationen och som har ungefär samma förkunskaper som du hade. Vad hade du velat veta?
- Kör texten genom ett rättstavningsprogram.
- Hjälp läsaren att navigera texten genom att dela in texten med underrubriker.

- Figurer skall vara numrerade och ha en tillhörande figurtext. En figur skall kommenteras i texten. I diagram och grafer skall på varje axel det vara tydligt angivet vad som hör till den axeln. Glöm inte enheterna.
- Ge figurer och tabeller ett konsekvent utseende. Var säker på att all text i figurer är tillräckligt stor för att läsas.
- Tänk på att presentera siffror med rimligt antal gällande siffror. Analysen av precisionen i era mätningar i samband med att ni presenterar utrustningen är till hjälp här.

Litteraturförteckning

Syftet med att ha en litteraturförteckning är att tydliggöra vilka källor du har använt för att skriva din rapport. Det finns en tydlig etisk aspekt i att korrekt referera till resultat som du använder - läsaren måste tydligt veta vad som är dina resultat och slutsatser och vad som hämtats från andra källor. Referenser kan också användas för att peka på var mer information kan finnas om till exempel en teori eller en uppställning.

Sådant som kan betraktas som allmängods behöver du inte referera till, är du minsta osäker så referera till en källa. Wikipedia kan i bästa fall betraktas som en sekundärkälla där du kan hitta referenser till verk du kan referera till.

Plagiat

Tänk på att om du kopierar en text rakt av utan att ange källa eller tar en bild någonstans ifrån utan att den är släppt ”Public domain” eller under en licens som tillåter modifiering/spridning löper du risk för att plagiera en källa. Plagiat är en form av fusk som du kan läsa mer om på https://www2.uu.se/student/regler-och-rattigheter/fusk. Är du det minsta osäker så fråga en lärare.

Example for the synchronisation between lectures and laboratories