Using Pre-lab Work to Improve the Quality of a Beginner Physics Lab

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Abstract

We have focused on developing a first-year physics lab on electromagnetism. Within this lab, we identified the key issues of a large knowledge gap, overloaded working memory, poor motivation, and difficulties connecting lecture material with the lab work, largely stemming from the fact that this is one of the first labs the students perform. Our goal was to present pedagogical tools to decrease the load on working memory, increase motivation and confidence, minimize the knowledge gap, and help the student reach a higher level of connection between knowledge and analysis. For this, we suggest using pre-lab videos to present important material, such as the set-up in combination with a pre-lab quiz, so that the students can practice and ensure they are well prepared. We also suggest introducing a flipped class session during the lab, focusing on the lab procedure. The quiz and lab procedure task provides formative assessments, while a lab report will be kept as the summative assessment. We believe that the tools we present will allow for more discussions during the lab and tackle the issues we have presented.

Background

For this project, we are looking at an electromagnetism lab from Introduction to University Physics, with Mechanics and Electromagnetism, the first physics course (Faculty of Science, 2019). The lab is together with one other lab, the first where the students go through the common lab process they will encounter throughout their studies. They have to prepare for the lab, which currently entails reading the manual and doing a simple quiz, performing the lab in pairs during an eight-hour session, and writing a report. The lab covers many of the course's intended learning outcomes, both related to *knowledge and understanding* and *competence and skills.* The learning outcomes from the course syllabus that are related to the lab are:

Knowledge and understanding

On completion of the course, the students shall be able to:

- *Describe and use mechanics and electromagnetism to solve conceptual problems.*
- *Account for the methods, ideas and preconditions of physics at a general level as a basis for studies in physics in general and mechanics and electromagnetism in particular.*
- *Describe elementary problems in mechanics and electromagnetism by means of vectors, dot product and cross product.*
- *Describe simple electric circuits with basic components.*

- *Account for the origin of magnetic fields, connections between these and current as well as their influence on charges.*

Competence and skills

On completion of the course, the students shall be able to:

- *Use measuring instruments relevant to the course.*
- *Based on given instructions carry out a simple critical analysis of experimental data.*
- *Carry out measurements and carry out, with supervision, laboratory work in mechanics and electromagnetism.*
- *Use the basic concepts, carry out calculations and solve theoretical problems in the mechanics and electromagnetism that the course contains.*
- *Write a laboratory report that follows a given principal layout and be able to account for the aim of the laboratory work, the methods, the materials used and to illustrate the results in the form of tables and figures.*
- *Give simple and basic constructive feedback on a laboratory report.*

Judgment and approach

On completion of the course, the students shall be able to:

- *Reflect, based on learning objectives and one's own aims, on progress regarding knowledge and skills.*

Whereas the *knowledge and understanding* learning outcomes can be related to the quantitative levels of the SOLO taxonomy, which will be defined in the next section, the *competence and skills* learning outcomes cover the relational and the *judgment and approach* learning outcomes the extended abstract levels.

A series of pedagogical challenges have been identified from the lab report and experience from the lab sessions. They are all connected and somewhat overlapping and will be summarized with some of the ways they have been detected. The challenges that we have identified are :

1. Since the lab is in the early stages of the program, the knowledge gap is larger since the student, to a greater extent, relies on their background, which will vary greatly. The gap applies to the concepts where the lecture material is new and challenging to some but not for others, but also to the practical skills. Practical skills include preparing for a lab, following instructions, working in a group, and writing a report. It is a pedagogical challenge to meet each student's needs without overloading some students' working memory or losing others' motivation. The knowledge gap is noticeable throughout the lab session, where there is a large variation between or within the pairs, and when aspects of the lab are discussed with the entire group, not all students participate.
2. The lab includes combinations of concepts from the lectures, some new and complex. Combined with the previously mentioned practical challenges such as following the instructions, using new equipment, and so on, it is noticeably challenging for many students. This often influences their ability to connect theory and experiment, leading to them unquestioningly following instructions without understanding what they are doing and resulting in more mistakes and a shallow understanding of the knowledge goals. This

can also be identified through the report, where the students can show a lack of understanding of what they have done throughout the lab and present results without showing an understanding of what they mean.

3. Points one and two can result in poorer confidence and less student motivation. The students with a lower prior subject experience and those with much experience will most often do the preparatory tasks that exist and the lab tasks themselves only "because it is required" (extrinsic motivation). It is a pedagogical challenge to show the connection to their overall understanding of the course's learning goals. This would require more room for discussion during the lab session, which is not always possible today.
4. The final aspect we have identified is the connection between concepts that the students learn during lectures or other course sessions and the lab material. This is identified through how the students describe concepts in their reports. For example, some describe the equations needed as "formulas for the lab" when they use them in the lectures to describe different concepts within electromagnetism. This is not only visible as a lack of understanding of the lab theory, but also in the students' view of the lab as a completely separate part of the course. All aspects are meant to work together, but there is currently a need to further clarify this connection.

Aim and Goal of the Project

The goal of this project is to address and provide possible solutions for the previously pointed out issues. Although the issues have been identified in a specific lab, the same approach can be used for other similar labs, not only for new students. This is especially challenging, considering that this lab is the first university-level lab that the students participate in. Therefore, the lab experience can be particularly overwhelming in several aspects. For this reason, we aim for

I. decreasing the load on working memory.
II. increasing the students' motivation and confidence when it comes to working in a lab.
III. decreasing the knowledge gap given by the different prior education of the students.
IV. the students to reach higher levels in the SOLO taxonomy, i.e., the students being able to connect the theory to the experiment and reflect on the results.

Before proposing different design approaches to achieve these goals in the next section, some theoretical concepts are described in the following, motivating the implementation of pre-lab activities.

Working memory, as mentioned in I., refers to temporarily storing, recalling, and converting information for problem-solving tasks. If the working memory is overloaded with information, i.e., its capacity is exceeded, the student's performance decreases as a consequence. Conventional lab exercises (performance of experiments along with following instructions, unfamiliar tools, documenting and observing the experiment) seem to overload the working memory. This is where pre-lab activities become interesting, as they lead to less occupation of the working memory during the actual lab. By conducting pre-lab activities, the long-term memory is activated, and it is easier for the students to distinguish between relevant and irrelevant information during the lab (Johnstone, 2006).

Regarding II., it was found by Agustian and Seery (Agustian & Seery, 2017) that performing pre-lab activities comes with further advantages: Not only do the students feel better prepared to carry out the experiments, leading to a decrease in anxiety and hence, an increase in confidence, but it also arouses more interest in the lab itself, i.e., the students feel more motivated.

Pre-lab activities are also a good method to take into account the knowledge gap (III.), since students with less prior knowledge can free some working memory space (I.) and become more confident beforehand (II.), meaning that possible errors during the lab can be decreased. The challenge for students with more prior knowledge is preventing them from losing interest in the lab. The advantage given by the pre-lab activities is then the increase in the students' efficiency. Therefore, the students spend less time on the lab exercise with more time for more complex and interesting questions and discussions as a consequence (Agustian & Seery, 2017).

The SOLO taxonomy (**s**tructure of the **o**bserved **l**earning **o**utcome), which was referred to in IV. is a method used to divide the student's performance into different levels, as illustrated in Figure 1. The performance increases from left to right. At the *prestructural* level, the learner misses the point, and no learning takes place. This is followed by the quantitative levels *unistructural* and *multistructural*, where facts and details can be listed. Qualitative learning starts at the *relational* level. As the name suggests, here the learner deepens the knowledge by being able to set facts in relation to each other and analyze them. The *extended abstract* level is the final level we hope for our students to achieve. This level goes beyond the learned information and does not lose the relational aspect. We hope to use pre-lab activities to cover the quantitative phase to be able to focus on the qualitative phase during (experiment) and after (lab report) the lab, with the students being able to connect the experiment with the theoretical background (Biggs & Tang, 2007).

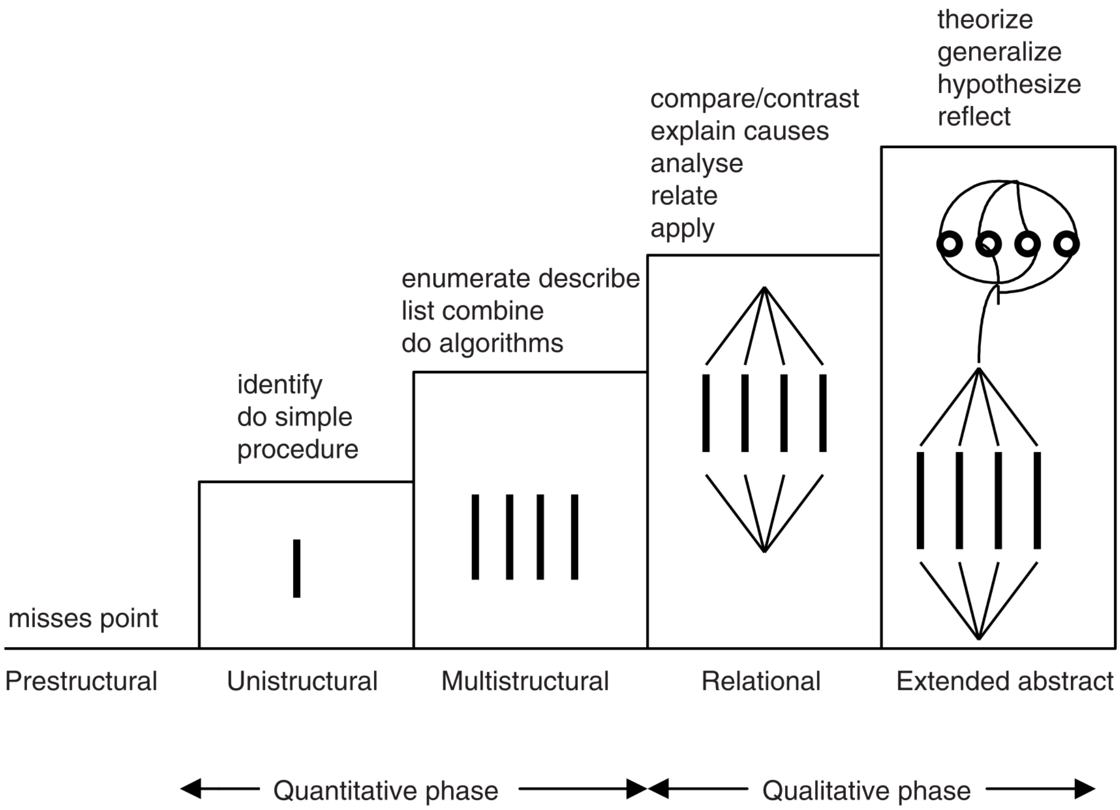

Figure 1 The five different SOLO levels (Biggs & Tang, 2007).

Design

To solve the reviewed issues and reach the proposed aims and goals mentioned above, we suggest the following three methods to consider before the lab.

1. **Pre-lab video lectures**

   Pre-laboratory lectures are among the most common methods to introduce relevant concepts and give experimental overviews before a real lab session. It helps students connect laboratory work with both their prior knowledge as well as the lectures. Students who attend pre-laboratory lectures not only have a better understanding of relevant concepts and the lab process but also feel better prepared to conduct experiments (Agustian & Seery, 2017).

   In this specific lab we discuss in this report, students are expected to measure the magnetic field in a solenoid with a device set-up that is hardly seen in daily life. Therefore, a video lecture with visual demonstrations of the lab set-up could make it easier for students to understand compared to verbal descriptions or diagrams in traditional lectures (Onyeaka et al., 2022). Moreover, the 24/7 accessibility and possibility of repeated viewing also accommodate diverse schedules (Aronne et al., 2019). It is reported that video lectures before a lab session can enhance students' laboratory experience, reduce the time needed to complete labs, and narrow the knowledge gap between students (Krishnankuttyrema & Shilov, 2020).

2. **Pre-lab quiz**

Pre-lab quiz is an effective way to assess students' learning outcomes before a lab session. The quiz should involve both basic theory as well as experimental procedure. We propose that a minimum passing score should be reached before attending the lab session to make sure students have acquired basic knowledge. The number of attempts is not limited so that students do not feel pressured to rush for a score.

Since the quiz aims to help students better prepare for the lab, each question could contain a few sentences that either explain the answer or indicate where to find the knowledge points. These explanations should be shown after completing the quiz so that students know why they are wrong.

3. **Flipped class with flowchart**

To reinforce students' understanding of the lab and refresh the experimental procedure, a short flipped class session could be conducted at the very beginning of the lab session. The idea of a flipped class is to provide information for the students to go through before the actual lab takes place, resulting in more time for discussion during the lab (Seery, 2015). In this first-year physics lab, our idea is that the students prepare a flowchart of the experimental procedure at home and discuss it within lab groups on the day of the experiment. Then, each group is invited to share part of their proposed flowchart with the whole class and discuss their answer with all the other classmates. In this way, students have the opportunity to discuss with each other and become more familiar with the experimental steps. It has been reported that flip teaching supports laboratory learning. Students who go through such flip class sessions experience less anxiety towards complex experimental steps and set-up, develop a better understanding of the relative theory and the procedures, and show higher work efficiency (Teo et al., 2014).

Disadvantages of the pre-lab activities:

We have mentioned a lot of advantages students could get from pre-lab activities. However, there're also a few potential disadvantages.

1. Time-consuming: pre-lab activities can take up a significant amount of time, both for students and instructors. Students may not have time to finish all the pre-lab activities and instructors need more effort to make instructions or materials provided for such labs.
2. Too much workload: If pre-lab activities are too intense, students may sometimes detract from other essential studying or coursework, resulting in the students not reaching all intended learning outcomes of the course.

3. Unequal preparation: Not all students might have equal resources or time to complete pre-lab activities. This could further enlarge the knowledge gap between students when they start the lab.

Assessment and Evaluation

1. **Formative Assessment**

Before the lab, the pre-lab quiz and fill-in flowchart are both methods to assess students' understanding of theoretical concepts, procedures, and materials related to the upcoming experiment.

We suggest adding some reflection questions to the lab instructions that the students can discuss within their groups. During the lab, we, as instructors, can walk around the laboratory and ask students questions related to their finished steps, current state, as well as expected results to monitor students' progress, increase students' engagement, promote students' critical thinking, connect the lab session with lectures, provide guidance and ensure that the lab session effectively covers the intended concepts and skills (Biggs et al., 2022). Some example questions are proposed below:

- What is the main idea here?
- How does the magnetic field strength vary inside and outside the solenoid?
- Where are we measuring the magnetic field around the solenoid?
- How are we measuring the magnetic field here?
- What factors affect the strength of the magnetic field we are measuring?
- What value would you expect?

2. **Summative Assessment**

After the lab session, a lab report should be handed in as a method of summative assessment. Since it is the first physics lab report for most students, the requirements of the lab report should be clearly stated. By describing the theory, the students demonstrate their quantitative knowledge about the experiment. Descriptions of the experimental setup and discussion of the results, as well as reflecting on them, helps to get an impression of the students' qualitative understanding. In addition to traditional lab reporting sections, some cognitive questions related to the lab can be added to encourage students' critical and independent thinking and help students reach the final level of the SOLO taxonomy (Feldon et al., 2010).

On the other hand, lab evaluation from students is a method to assess the students' attitude and feedback towards the lab session, especially the role of pre-lab activities. This is a more direct way of evaluating the effects of the proposed methods on students' learning. This evaluation could include questions such as:

- Did you feel like the preparatory videos helped you prepare for the lab?

- Did you feel like the preparatory quiz helped you understand the material?
- Did you feel like the questions in the lab report were helpful for your understanding of the lab?
- Do you feel like the lab was complementary to the lecture material?
- How was the workload before the lab?

Conclusion

In conclusion, in this project, we delved into a first-year physics lab focusing on electromagnetism. The primary problems we identified included the knowledge gap, overloaded working memory, lack of practical skills, insufficient understanding of the experiment-theory connection, and poor motivation - mainly caused by the fact that this is the first university physics lab the students attend.

To address these issues, we have focussed on enhancing pre-lab activities. We suggested several design approaches, including the implementation of pre-lab video lectures, adapting the pre-lab quiz by including a minimum passing score and explanations of the answers, and introducing a flipped class session where the students fill out and discuss a flowchart of the experiment's workflow.

For assessing the students' performance, we recommended the pre-lab quiz, flowchart, and questions asked by lab supervisors as formative assessments. We suggested keeping the lab report as a summative assessment to evaluate the students' understanding of the experiment.

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For the background, we got the feedback to combine some of the pedagogical challenges since they are very similar. They are very connected, but important differences tie into our aim and design, so we chose to clarify the points a bit instead. We were also asked to add the learning goals of the lab. Since these are not defined, we added the learning goals of the course that apply to the lab.

For the aim and goal of the project, our peer review group asked if we could not make the aim broader to apply to other lab situations. We agree that what we have in the report is not only true for this lab, but we still chose to keep it this way to make it a more concrete case. However, we added a sentence that clarifies this. We were also asked to change SOLO *stages* to *levels*, which we accepted and changed in our report.

We were asked to add some cons to our report so that we would not only focus on the positive aspects, and discuss the workload of pre-lab. This has been added as a new section, “Disadvantages of the pre-lab activities”. We have made the flipped classroom task clearer since it was misunderstood what this task entailed during the feedback session. We have also made it more clear how we can assess higher SOLO levels via the lab report and avoided the word “learning style” in our report. We got feedback on the assessment that we could add some peer discussion. We always intended to have this as a part of the questions during the lab, so we now state this more clearly. We also got the feedback that having examples of evaluation questions could be good. Examples can make our intentions with this more understandable, so we added a short list. We also added page numbers at the lower right corner of each page of our lab report.