Improving students’ understanding and independence by active learning in laboratory activities

A group project report in the course NAMN005
Group 7

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Abstract

In this study we provide different active learning solutions to students' lack of independence and understanding observed in different lab learning environments. The solutions here presented are designed to be implemented pre, during and post lab. For pre-labs the main solutions are using blended learning techniques such as videos with quizzes incorporated, as well as giving students more freedom when planning for the laboratory. In the case of in the lab solutions, the main approach is to summarize at the end of the day as a way to reinforce reflection on the newly acquired knowledge. Finally, post-lab approaches are to use assessment as a way of learning and to standardize feedback and evaluation criteria in the form of a grading rubric.

Aim and goals

This paper presents three different laboratory exercises to illustrate common problems in student's learning in labs. These problems are lack of independence and confidence, poor reflection in the laboratory and the unclear role of the lab report in learning. The examples are divided into pre-lab activities, activities in the lab, and post-lab activities. The aim is to use relevant literature to analyse the problems, and to propose solutions grounded in theory. As an appendix, concrete example solutions are presented. Common theories used for analysis are the SOLO taxonomy (Biggs & Collis, 1982) and cognitive load theory (Figure 1).

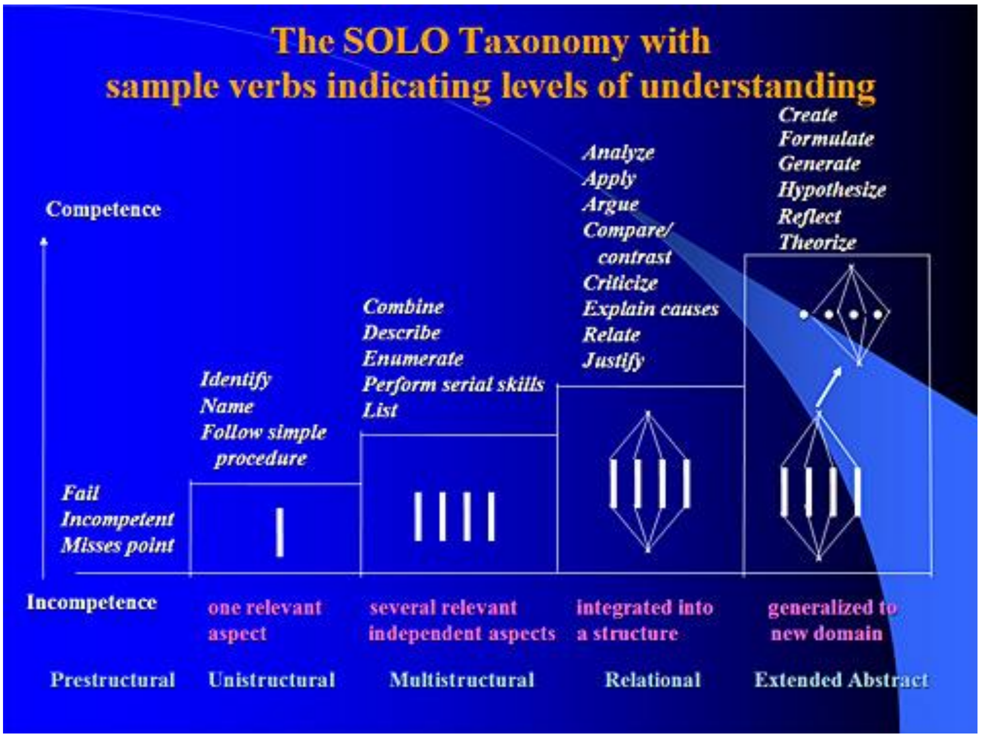

Fig 1. SOLO Taxonomy. Biggs & Collis, 1982

Pre-labs

Overview

This section will describe how pre-labs could be used to improve students' autonomy and confidence in a general chemistry lab. The lab is one out of four labs given in the course KEMA20 Chemistry: General Chemistry (15 credits, First Cycle course). It is the first course taken by students who study a bachelor of chemistry. Students are therefore very unfamiliar with common laboratory techniques. This is reflected in the course syllabus, which has the following Intended Learning Outcomes related to the labs:

> *The laboratory exercises aim to provide skills in laboratory methodology by enabling students to practise planning and executing chemical experiments in small groups.*
>
> ***Competence and skills***
> *On completion of the course, the students shall be able to*
> · *perform elementary laboratory activities, in accordance with the description provided, and present theory and laboratory results in a final report*
> · *assess the risks associated with chemicals, and manage them safely*
> *(Lund University, KEMA20 syllabus)*

One of the laboratory exercises is to separate two compounds in a mixture based on solubility using a separation funnel. The goal of this lab is to familiarize students with a common laboratory technique (separation funnel), apply the concept of pK_a and to learn how to write a lab report. At the moment, the pre-lab activities consist of a 13 min video and a 15 min lab introduction given by the TAs right before the lab.

Problem

In my experience, analysing this based on the SOLO taxonomy (fig 1.) reveals that many students manage to get a unistructural or multistructural understanding: they can perform an extraction at the end of the day. Lab reports however reveal that many students do not arrive at a relational level where they can connect the concepts to what they did in the laboratory. Another issue with this laboratory exercise is that many students lack confidence in the laboratory, and need a lot of scaffolding and help.

Analysis and solutions

Solutions to the issues mentioned above are based on cognitive load theory, and studies on how pre-lab activities can improve the affective experience (Agustian & Seery, 2017). Based on observations in the laboratory, there are indications that students suffer from excessive cognitive load (Reid & Shah, 2007). Often students fail at simple tasks they would have no problem performing outside of the laboratory, such as turning on a heat plate, or how two liquids behave based on their density. Studies have shown that pre-lab videos or interactive simulations increase the time spent on preparation, but the overall time needed for completion of the lab (pre-lab activities + lab exercise) decreases (Box et al., 2017; Burewicz & Miranowicz, 2006). An implication of this is that the autonomy of the students increases. A strategy providing students with information in advance enables the storage of this information in the long term memory, thus reducing the cognitive load when completing the task (Agustian & Seery, 2017). An interesting finding is that the time required for analysis also decreased, indicating that the understanding was improved compared to when given only written instructions. This would improve the outcome of the lab activity related to the ILO "performing elementary laboratory acitivities".

Little research has been focused on the affective component of pre-lab activities. (Agustian & Seery, 2017). However, as a beneficial side effect from pre-lab simulations and videos, it has been noted in several studies that student confidence increases when doing these pre-lab activities.(Chaytor et al., 2017; Chittleborough et al., 2007) Students feel more prepared and confident in the lab, making them more autonomous. Open-ended questions in the former study indicate that pre-lab activities help with anxiety "[Watching the videos] eased my anxiety about lab experiments because I felt more prepared." (Chaytor et al, 2017, p. 865)

Based on the theories above, that pre-lab activities can reduce cognitive load, increase confidence and enable students to reach further on the SOLO-taxonomy, some improvements to the pre-lab activities could be proposed for the separation-lab in the General Chemistry course. First, it should be seen as an integral part of the lab activity. As the video is not mandatory, and it is not checked that the student's actually watch the video, many students do not spend time on understanding the contents of the video. A quiz integrated into the video, with feedback based on the student's response, could improve the learning from the video. The video could in that way also be split into shorter sections. Dividing the video into a pre-lab and a post-lab video (regarding writing of the lab report) could also help the students to access the information when needed (Schmidt-McCormack et al., 2017).

Furthermore, Agustian and Seery (2017) make the difference between procedural vs supportive information. Procedural information relates to specific details and experimental protocols, and supportive information is about the underlying theory. Because supportive information is not necessarily needed to complete the lab, it is better not presented during the lab in order to relieve cognitive load. On the other hand, having seen a procedure beforehand might also help to decrease cognitive load during the lab, and increase confidence. Reid and Shah (2007) argue that laboratory manuals should be less of a "recipe book", and that students should be "encouraged to plan the actual experiment, and see why it is they are doing what they are doing". In the case of the separation lab, this could be done by teaching them the principles of extraction, and then letting them plan themselves in which order they want to do the extractions. Having the students plan their own lab gives them responsibility and control, which might be positive in terms of students' confidence in the lab. This also relates directly to the ILO of "enabling students to practise planning and executing chemical experiments".

It is important that pre-lab activities do not increase the overall time needed for students to complete the laboratory exercise (Agustian & Seery, 2017). As mentioned above, studies show that if the pre-lab activity is carefully planned, the overall time spent can actually decrease. (Box et al., 2017; Burewicz & Miranowicz, 2006). Also the pre-lab activities should have a clear goal and not be too long, as this will decrease motivation amongst students (Reid & Shah, 2007). On a personal experience, it is also important that students have access to computers were they can perform these activities, as not all students have access to a calm home environment with high speed internet.

The benefits from pre-lab activities, such as greater understanding and independence will also benefit students in a future career, which motivates them to be used more extensively.

In the Lab

Overview

In this section we are going to focus on the implementation of active learning techniques that would improve the student's experience in the actual laboratory. To provide a context, we are going to use the laboratory of the course BIOR79: Methods in Molecular Biology as an example. According to this course syllabus, the learning outcomes related to the laboratory are: to some extent independently apply methods in molecular biology; plan and evaluate experiments addressing questions in molecular biology; and evaluate, assess and critically compare results from studies in molecular biology. Here it is also stated that the laboratory will be used to apply some of the molecular biology methods and they would be linked to the theoretical parts. The laboratory will also provide the students with some degree of possibility to plan and carry out experiments independently.

The lab consists of the students performing two different methodologies involving several experiments and principles. Usually, the experimental part of both methodologies takes around 1 week followed by some analysis and later by assessment. At the end of the first methodology, the students are expected to deliver a laboratory report in the format of a scientific article.

Problem

At the time of the assessment, students had to explain the principles and background of the experiments and the methods they used, and then analyze and discuss the results. When reading students' reports, it was evident that some of them were not really associating the concepts to each other in the right way. Using the SOLO taxonomy scale (Fig.1) and reading their lab reports, these students could be placed at the Multistructural level, where they could perform several skills and understand each experiment, but not really associate one concept with the other, at least not in a correct way. This is truly problematic since from the learning outcomes listed before, they are expected to reach Relational or even Extended abstract level from the SOLO taxonomy.

Another situation was that when in the laboratory students were asked by lab assistants (Abraham) about the reasoning behind experimental setups, most of them were not able to provide a correct answer. It seems that during the laboratory time, related to the overload described in the previous section, students tend to focus on following the provided laboratory manual instructions without thinking of the principles being tested or the logic behind the laboratory procedures. It seems they fall into a comfortable situation where instructors have a providing role of lab equipment, instructions and explaining, while students are just recipients of the knowledge and unquestioningly follow the laboratory manual as a recipe.

Analysis and Solutions

It would seem as if the laboratory was not successful at providing enough learning, or at least not for all the students, to achieve the intended learning outcomes of the course. As explained by literature, in the laboratory a Kolb model is usually used, where learning begins with active experimentation followed by a concrete experience, and later by some reflection which leads to conceptualization (Davis & Arend, 2013). One of the reasons why the knowledge is not getting reflected as intended in student's answers and reports could be that there is little or no time for the reflection part of the cycle. This step is quite fundamental and without it the Kolb cycle gets interrupted. Reflection in experiential learning is a pedagogical tool and it enhances and accelerates learning (Davis & Arend, 2013).

One way of promoting reflection in the laboratory could be to make students track their learning periodically during the laboratory time, since usually there is extra time scheduled or waiting times in between experiments. This could be done by several activities.

Summing up is a habit that is recommended for reflection (Ward et al., 1997). This could be done either by using a questionnaire with different questions intended to place a student somewhere in the SOLO taxonomy or something even more active like a minute paper. This minute paper or questionnaire should include some of the following: summary of the experiments of the day, the key points of the procedures, linking the practical with the theoretical part of the course, and should ask about remaining doubts or questions arising from the practical. These activities could be done individually in an anonymous way, so students feel encouraged to write down their concerns and doubts. After collecting the minute papers, it is important to discuss and address the most common doubts. The main advantages of this solution is that it can be done anonymously and students are not afraid to ask since they are not under a spotlight, and also that it is a way of formative assessment. The disadvantage could be that it would take extra time to read the minute papers and answer the most common doubts during the next day. However, this time gets compensated with better lab reports at the end.

Another way to perform a summary activity is to discuss and troubleshoot with peers about what has been learned and the results from the experiments on a particular day. As stated in literature, this encourages a team dynamic and prompts peer conceptual thinking about experiments (Robinson, 2005). This activity could be complemented by having to write a short summary of the day with the main concepts and methods learned during the day. The main benefit of this solution is that it encourages discussion and students may open up easier to a peer than to a teacher. However, this could make difficult to evaluate individual progress.

Regarding laboratory assistant practices, it could be helpful to be sure to approach students in need in the best possible way. Usually, instructors stay aside waiting to be summoned by students, this might not be very popular for students, since asking for help would become a public event. Literature suggests to rather try to spot students in need of assistance but also avoiding picking on specific individuals. This could be done through systematic or even random visits to each team or each student (Ward et al., 1997).

Post-lab

Overview

This section is aimed at investigating the assessment of the lab, and how to make the assessment process smoother. As an example, in an introductory course in molecular biology that I am teaching in, the following is stated in the course syllabus.

> ***On completion of the course the student shall be able to:***
> *use basic methods in molecular and cell biology*
> *interpret laboratory results based on literature*
> *communicate orally and in writing in a basic scientific way*
>
> *(Lund University, MOBA03 syllabus)*

These are essentially the pedagogic goals that the lab is supposed to handle alone. In the appendix are the "Lab Report Instructions" given to the students for writing a report and the relevant assessment criteria. The focus is on describing a form for the report in order to "homogenize" the student hand-ins. A short description of the assessment criteria is also presented. An attempt to encourage some type of student interaction is included in "can the report serve as a study material for a student who has been ill", but the chance is abandoned there. There are instructions for writing this specific report, but the students don't get a good explanation of what is scientific writing.

The Problem

Laboratory exercises are often mandatory, but apart from the student's presence and active participation, assessment is often difficult in my experience. Demanding certain experimental results is rarely a reasonable alternative as other factors than the student's skills or knowledge play a too large part. It is of course possible to assess the knowledge of the subject and understanding of the exercise by the use of more traditional exams, but in practice the courses we teach combine the assessment of labs with an exercise in scientific writing: a lab report. The aim of the lab report is mainly to assess the intended learning outcomes of the course, but is also responsible for teaching students to interpret results.

Producing a written text can be a very good exercise for the students, but the workload can often get out of hand, both for the student and the teacher (Felder and Brent, 2016). I have noticed that if students feel unsure of what they are supposed to do, they might spend too much time discerning what the teacher "actually wants", and too little time learning and reflecting. On the flip side, teachers could spend ages writing extensive feed-back for a student, who will throw a glance at the grade of the report but not even bother reading the valuable help that the teacher has offered.

A large concern in this combined assessment and writing exercise is whether the students actually learn how to write a lab report. Different teachers offer different ideas of what should be included in the reports, but do the students actually learn how to write scientific texts?

Analysis and Solutions

Felder and Brent give four general criteria for evaluation of reports validity, reliability, fairness and efficiency. In essence they say that the grades should show how well the students performed in the current work independent of previous performances, that the same report should be valued similarly by different teachers, that the students should be aware of the grading criteria, and that the process is not unnecessarily time consuming. The method for doing this is, they explain, to construct a “checklist” or “rubric” that formalizes an otherwise very subjective process. They also suggest student interaction through the use of peer review to both make the process more efficient, but also to add a chance to reflect upon their own work. In the appendix is included an example of how a grading rubric could be designed. (Felder and Brent, 2016)

To help the students in taking in the content of the lab, there is a need to make the process more predictable for students and teachers. The lab report instructions should include some formal definition of what is required to pass, and it should be presented to the students so that they understand what it means. For the teacher, there could also be a standardized feedback list with comments to common problems to stream-line the correction process and increase the reliability. This entire process could also help the learning of scientific writing. Students could even be told to give peer-feedback based on the rubric to further promote learning and reflection. On the flipside, I have noticed that some teachers are reluctant to provide the students with too much instructions for report writing. This is reasonable, since the students might just copy the given information without thinking. This has to be considered when designing the grading rubric. The grading rubric is also not very good at handling cases outside the norm, and cases of excellent writing or severe problems could be overlooked if it is followed too zealously.

Assessment of the proposed activities

So how do we know if the students actually learn what we want them to? We have throughout this report used lab reports to identify the problems we experience in laboratory teaching and learning. This is also the first tool we could use to assess the student learning, and most of our questions could be answered here. To tell if the students have arrived at a relational level where they connect what they learned in the lab, one would have to look at the discussion they write in their reports to tell how well they handle the different parts. However, if a student hasn’t managed to connect what they learned in the lab, how do we tell if this is because of learning overload or some other reason? For this assessment evaluating the minute papers and following discussions is key to get continuous information on how the learning process goes.

To know if the grading rubric works, one should compare it to an older assessment method and see how the quality of the reports have improved. The goal is after all to make the students learn more, and only looking at the number of students that pass the course would not be the most telling thing.

Conclusion

The laboratory exercises need to be seen from a holistic point of view, where there is consistency and planning from pre-lab activities via the lab exercise to the lab report. Having students actively engaging in teaching material and reflect on what they are doing, will improve their learning according to the literature reviewed in this paper.

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Process report

Everyone in the group contributed in planning the project and actively discussed the project in regular meetings. The pre-lab section was written mainly by Jesper, the in the lab section mainly by Abraham and the post-lab section mainly by Balder. Overall, the collaboration went very well.

Feedback summary

The title was updated to better reflect the problems addressed in the report. Along with this, we have made clear in the aim and goals, as well as in the abstract, what are the challenges faced in laboratories. We decided on this, because we agreed that it is important to be specific about what we are tackling with the proposed solutions. A SOLO taxonomy figure was added at the beginning of the text so the reader may refer to it, since it is often mentioned. In case the reader is not familiar with it, it would give more context about the situation of the students and the intended improvement.

In all parts of the report where it was not clear if personal experience or literature was used as a source this was clarified. Possible disadvantages to the solutions in each section were added, since no method is flawless. The solutions were also related to the ILOs for the specific course. A quotation was removed from the post lab part since it is not really necessary to use a quote to reference individual terms. The grading rubric was altered to be more specific, but it was intentionally left somewhat unspecific to allow for flexibility.

Appendix

Quiz questions for a pre-lab in KEMA20, General Chemistry

In what form are the different compound classes at these pH?

a) pH 2

b) pH 8

c) pH 14

Is a compound soluble in diethyl ether when it is charged or uncharged?

What is the difference between extraction and washing?

In what order would you do the extractions?

How is the pK_a of a substance defined?

How can you assess the purity of a compound by it's melting point?

Describe how you use a separation funnel:

Why is it important to vent the separation funnel?

What is the role of $MgSO_4$?

Example of minute paper activity

At the end of everyday practical students should take 5-10 minutes to reflect on provided questions and write down a minute paper. Minute papers should be written down anonymously and should be collected at the end of the lab by instructors.

Guiding questions for minute paper for BIOR79 laboratory course:

- What methods did you learn during today’s session?
- Summarize the main steps of today’s protocol
- What’s the principle behind today’s laboratory technique?
- How were your samples transformed or processed today?
- What were the critical steps?
- Write down the remaining doubts or arising questions from today’s practical

After reading, the recurring doubts should be addressed during the next session waiting times.

Grading Rubric

CATEGORY	1 Needs Improvement	2 Good	3 Excellent
Format	Some parts mentioned in the lab instructions are missing.	All parts mentioned in the lab instructions are included.	The layout is clear and makes it easy to follow the red thread.
Understanding of lab concepts	Some concepts are incorrectly explained or not used to describe the data.	The concepts are correctly explained and used to describe the data.	The concepts are used to make comparisons and relate the data to that found in literature.
Scientific writing	The report is not written as a correct scientific article according to the material provided.	The report is written as a correct scientific article according to the material provided.	The student has shown understanding of scientific writing in the peer-feedback process, and reflects on their own writing.
Figures and tables	Not all relevant figures and tables included or lacking captions.	All relevant figures and tables included with captions.	The figures and data are used to describe important concepts, and to make comparisons between results.

Lab Report Instructions

Take notes while working in the lab!

Each lab group writes a report in English for each laboratory performed. The report consists of a maximum of 1200 words, excluding figures and tables. It is organized as a scientific article and contains:

- **Title**
- **Authors**
- **Course**
- **Date of report**
- **Introduction:** Give a brief background to the issue and justify the investigation.
- **Results:** Here, the results are presented in detail using numbered tables and figures. These shall include legends, so that they are understandable by themselves and not dependent on the rest of the text. All pertinent observations also described in the text (If you have not in the text described a change that is visible in the figure, we cannot know that you have seen it!). You should not include individual calculation.
- **Discussion:** Here you interpret the results and conclude by comparing observations with what the literature (*e.g.*, Alberts et al., 2014) says. Here, you also discuss possible sources of error.
- **Materials and Methods:** Summarize the main procedures (The compendium contains the details, which you should not copy).
- **References:** Here you list the literature you cite in the text.

Example:
Alberts B et al. (2014) Molecular Biology of the Cell, 6th Ed., Garland Science, pp. 111-222.
NB! Do not forget page numbers!

Submit the report via canvas as pdf or docx as instructed by the assistants. Primary data (photos, oxygen curves, etc.) is made into an appendix and submitted in canvas. Additional instructions will be given by the teacher or assistants.

The report is assessed by the assistants, from the perspective: Does the report show that you have understood the lab and what it highlights, and can the report serve as a study material for a student who has been ill during the labs to benefit from the same afterwards. The report is assessed as pass or fail. In the latter case it must be corrected and submitted again. Absolute deadline for submission of the revised version is three working days before the course ends, at 16:00. This is the last chance to get reports approved; Reports that are submitted late or who need further revision will not be corrected until the next time the course is offered.

Approved lab reports are required to pass the course.