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Translation of a practical laboratory exercise into a theoretical laboratory exercise

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Background and introduction to teaching intervention

Within STEM fields(science, technology, engineering and mathematics), experimental laboratory work is an essential part of university degree level curriculums (Russell & Weaver, 2011). This is also the case for the Bachelor's Degree in Pharmacy at the University of Copenhagen (Københavns Universitet, 2021).

The learning outcomes of laboratory teaching are multidimensional, but can be categorized into five competency clusters: *Disciplinary learning*, *experimental competences*, *affective outcomes*, *higher-order thinking and epistemic learning,* and *transversal competences* (Agustian, Finne, et al., 2021; Agustian, Nielsen, et al., 2021).

For several reasons it can sometimes be necessary to translate a practical laboratory exercise into a theoretical laboratory experiment, e.g. due to lack of laboratory space and time, lack of equipment and instrumentation or lack of teaching personnel. This will inevitably change the learning outcomes, and especially the learning outcome of "experimental competences" will decline, while the learning outcomes of other competency clusters ideally will be elevated.

In the course, "Evaluation of Pharmaceutical Substances", the second laboratory module contained too many sub-exercises. This resulted in stressed students due to time pressure and strained teaching personnel. Furthermore, most of the teaching personnel's time was mainly used to solve practical questions, without having time to bridge the practical laboratory exercise with the theoretical part of the course (Trabjerg, 2020).

To mitigate this challenge one out four sub-exercises in the second laboratory module was adapted into a theoretical laboratory exercise. Whilst similar in design to a practical exercise, a theoretical laboratory exercise does not require the students to perform the exercise themselves. Instead, they are provided with experimental data, which should be used to prepare a report scheme.

The purpose of the current study was to describe the development and evaluation of a theoretical laboratory exercise concerning a complexometric titration. Due to the COVID19 regulations, it was not possible to fully investigate the effectiveness of the new alterations in the second laboratory module. Thus, it is not known if they would have resulted in a reduction of the time pressure on the students and the strain felt by the teaching personnel. Hence, the evaluation is focused on the students' learning outcome of the adapted exercises.

Course description

The course "Evaluation of pharmaceutical substances" is a mandatory course for second semester students in the Bachelor's Programme of Pharmaceutical Sciences. Approximately 240 students enroll each year. The course is structured around four laboratory modules and a final laboratory project. Each module has a different theoretical focus, e.g. pH titrations, titrimetry, spectrophotometry and quantitative analysis of "large biomolecules". Around each laboratory module there are several other teaching activities, e.g. one lecture, one intro class-based teaching situation (45-90min) and one outro class-based teaching situation (45-90min).

Approach and method of analysis

A laboratory exercise in the course "Evaluation of Pharmaceutical Substances" concerning complexometric titration was converted from a practical laboratory exercise into a theoretical laboratory exercise.

To evaluate the learning outcome of the adapted exercise and the students' experience of the adapted theoretical exercises three semi-structured interview were performed with groups of 2-3 students.

The interviews were separated into two different segments. The purpose of the first segment was to assess the students' learning outcome of the theoretical exercise (complexometric titration) compared to their learning outcome of a practical exercise (redox titration). The two exercises were conducted simultaneous by the students in the second laboratory module. Practically, the interview groups were asked to draw mind-maps or to generate word association list of the two different exercises. The resulting mind maps and word association lists was used as a proxy to assess the learning outcomes of the students and their knowledge of the underlying theory (Appendix A).

The purpose of the second segment of the interview was to further investigate the students' experience of the theoretical laboratory exercise to identify positive and negative factors that affect the students' learning outcome of a theoretical laboratory exercise. Relevant statements concerning the aims of the current study from the interview was transcribed and structured by themes.

The interviews were conducted in Danish and the author translated all quotes from the interviews presented here.

Results

Development of teaching material

Three new teaching materials were prepared to improve the learning outcome of the students: redesign of the laboratory protocol, production of a video to visualize the exercise and the development of a report scheme that was tailored a theoretical exercise instead of a practical exercise.

The new laboratory protocol was redesigned to accommodate the translation of the exercise into a theoretical exercise. The focus on the protocol was on the different steps of a complexometric titration and the associated materials. A video of the exercise was produced, where all steps and materials in the complexometric titration was shown, with emphasis on the color change at the end point of the titration.

Finally, the report scheme was modified to accommodate the translation into a theoretical exercise. As the *experimental competences* will not be developed in a theoretical laboratory exercise, it leaves room to focus on some of the other *competency clusters*. Especially *disciplinary learning* and *higher-order thinking*. *Disciplinary learning* was promoted by focusing on bridging of the experimental and theoretical part of the course. While *higher-order thinking* was promoted by incorporation of a table in the report scheme, where the students should explain the purpose and function of all steps and materials used in the exercise (Appendix B). The development of the table was highly inspired by the recent use of flow charts to promote improved learning outcome in an laboratory exercise described by Grosskinsky and colleagues (Grosskinsky et al., 2019).

Comparison of mind maps and word associations lists

A qualitatively assessment of the mind maps and word association lists (Appendix A) was performed. It is evident that two out of three groups have comparable learning outcomes of the practical and the theoretical exercise, while the last group had a markedly decreased learning outcome of the theoretical exercise compared to the practical exercise.

For the two groups with a similar learning outcome the associated words points not only towards the execution of the theoretical exercise, but also the underlying theory. Both groups mention “back titration” as the titration principle. Furthermore, both groups also included other qualified theoretical discussions. To mention a few: the importance of affinity of the secondary metal ion towards *EDTA,* and the mechanism of action of the metal ion indicator *Mordant Black*.

Analysis of semi structured interviews

The theme structuration of the interview resulted in eight different themes. I have chosen to focus on two overarching themes, as these seems most important in a successful translation of a practical laboratory exercise into a theoretical exercise: tailoring of teaching material and curriculum and deprioritization of a theoretical laboratory exercise.

Tailoring of teaching material and curriculum

For a successful adaption of a practical laboratory exercise to a theoretical laboratory exercise, it is important that the teaching materials were tailored towards the new format of the exercise. Several times the students underlined the importance of even more detailed and step-by-step exercise protocols than for practical exercises, as the connection with the practical setting is lost.

Furthermore, all groups highlighted the importance of a visualization of the theoretical exercise, as the most important single parameter to promote understand and improve the learning outcome of a theoretical exercise. The more visual the exercise is the better, e.g. a color change, a precipitation or a similar change that is easy to observe.

> *I do believe that it makes a big difference, when you actual can see a color change… It is just easier to understand the importance of every material, instead of just reading it on a piece of paper… I do also think that videos are a really good idea.*

Several of the students also noticed that it is extremely important that a thorough introduction to the underlying theory should be conducted before the theoretical exercise to promote a positive learning experience. To perform a practical exercise, without any previous introduction of the underlying theory is demanding, but feasible, given the right teaching material. However, to perform a theoretical exercise without prior introduction to the underlying theory are extremely difficult, and is according to the interviewed students not a positive experience.

> *I did miss some theory… Just to conduct a theoretical laboratory exercise, to some theory that we have not been taught yet. I thought it was really difficult…*

De-prioritization of theoretical laboratory exercises

The second major finding in the current study is that the theoretical exercise was highly de-prioritized by the students. This concerns both the preparation phase and when they entered the teaching laboratory.

> *… Cool, now we can focus on A, B and C, and then number D, that is just; yep, yep, yep, let us just get some numbers…*
> *…I have first looked at it (the theoretical exercise) afterwards…*

The de-prioritization of the theoretical exercise is also evident in the students' study approach to it. Several students described a surface approach to the theoretical exercise, as they did first look at the exercise and report scheme after they left the teaching laboratory. Furthermore, they primarily focused on how to fill-out the report scheme instead of focusing on understanding the exercise and the underlying theory.

> *… you read the report, read the questions, answer the questions and then forget everything again…*

> *... what you learn at the university is to be solution oriented. We have to prepare this report scheme, and then we find the answers, without reflecting further...*

Several of the groups also pointed out that a way to mitigate the students' surface approach towards learning and the theoretical exercise is to tailor the report scheme, in a way that a deeper understanding of the exercise and the underlying theory is needed to complete it. The students highlighted the table in the report scheme, where they had to describe the function of every single step and materials used in the exercise, as a way to promote deep learning of the underlying theory and general chemical principles (Appendix B).

> *It was really good. Because I can remember how EDTA worked, which we should use in the protocol (for the final project in the course). And the reason why I knew it, was because I have learned it in the exercise concerning aluminum sulfate. It worked quite good that we had to write, why you had to do it. It sticks...*
> *...(the table) forced you to think about the mechanisms behind, instead of just answering the assignment. Of cause, it was a part of the report scheme, but you were forced to learn more about these things...*

Discussion

The learning outcome of the theoretical laboratory exercise were, for the majority of the groups, kept at a similar level as a comparable practical laboratory exercise. However, for one group a markedly lower learning outcome was achieved. The current analysis points toward the importance of mitigating the internal de-prioritization of the theoretical laboratory exercise by the students. This can be done by active intervention by the laboratory supervisor and by the design of the teaching material, especially the assessment part.

The laboratory supervisor can mitigate the de-prioritization by 1) articulating the importance of the theoretical laboratory exercise and 2) making specific time slots for every single group in the confrontation time in the laboratory, where the laboratory supervisor facilitates a discussion of the theoretical exercise. By articulating this before the actual laboratory module, the students will hopeful prepare the theoretical exercise beforehand

and a discussion will allow the supervisor to discuss the underlying theory and bridge the laboratory exercise with the theoretical part of the course to promote high-quality learning.

The importance of tailoring the teaching material is not a surprising finding in the current study, and is accordance with two prominent models on how to promote high-quality learning: Biggs' model of *constructive alignment* (Biggs, 1996) and the concept of *congruence* developed by Hounsell and co-workers (Hounsell et al., 2005; Hounsell & Hounsell, 2007). Both models describe, that alignment between teaching activities, intended learning outcomes and assessment are crucial to promote high quality learning. The teaching material can be seen as a part of the teaching activities and should be aligned with the intended learning outcomes and the assessment.

Furthermore the "back wash" effect (Biggs, 1996), which describes how the assessment affects the students learning focus are also highly evident in the current study. This further highlights the importance of how the report scheme is designed to mitigate a surface approach to learning, which several of the students articulated in the conducted interviews.

Although not the focus of the current study, a possible positive aspect of theoretical laboratory exercise that could be explored further is that the format is highly flexibility and markedly enlarges the room for creativity. In a theoretical exercise, it is possible to develop exercises that will resemble real-world laboratory work either in a research lab or in an industrial setting. In a teaching lab most exercises are developed to provide the students with expected and useful data in at least in 90% of the time. However, this is not the case in a research laboratory. Here, not all experiments are working at first try, and way more time is used on troubleshooting an experiment and the associated instruments. In an industrial setting, e.g. in a quality control laboratory, the educated pharmacist will not themselves be conducting the experiments, but will troubleshoot the experiments, when non-expected results are achieved.

Conclusions

The current study has highlighted some pitfalls and ways to mitigate these in the process of adapting a practical laboratory exercise into a theoretical laboratory exercise. First, the teaching material needs to be tailored to accommodate the theoretical nature of the exercise. Ideally, the teaching material should contain a thorough step-by-step protocol and a video of the actual exercise.

Secondly, it is important, that the assessment (e.g. report scheme) promote higher-order thinking to elucidate the connection of the exercise with the underlying theory.

Finally, it is crucial that the supervisor stresses the importance of the theoretical exercise and actively engage in discussion with the students concerning the exercise to mitigate students' internal de-prioritizing of a theoretical laboratory exercise.

References

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A

Mind maps and word association lists

Interview group 1

Figure 1: Mind Map or word association concerning the practical laboratory exercise "Quantitation of acetyl cysteine".

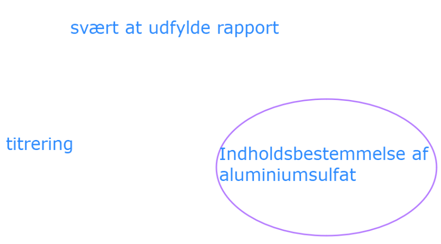

Figure 2: Mind Map or word association concerning the theoretical laboratory exercise "Quantitation of aluminum sulfate".

Interview group 2

Figure 3: Mind Map or word association concerning the practical laboratory exercise "Quantitation of acetyl cysteine".

Figure 4: Mind Map or word association concerning the theoretical laboratory exercise "Quantitation of aluminum sulfate".

Interview group 3

Figure 5: Mind Map or word association concerning the practical laboratory exercise "Quantitation of acetyl cysteine".

Figure 6: Mind Map or word association concerning the theoretical laboratory exercise "Quantitation of aluminum sulfate".

B

Table describing the function of the single steps and materials in the theoretical exercise

Text in gray are the correct answers in the boxes that should be filled-out by the students.

Udfyld de tomme felter i nedenstående tabel ud fra informationer fra Ph.EUR. som vist på s. 67 i kompendiet. Beskriv de enkelte skridt, som indholdsbestemmelsen af aluminiumsulfat i Ph. Eur. består af.

(Anmærkninger til uddrag fra Ph.EUR. på s. 67 i kompendiet:

- Under ”Assay” er skrevet ”dissolve 0.500 g in 20 mL of water R”. Denne sætning erstatter sætningen i kap. 2.5.11. Complexometric Titrations – Aluminium ”Introduce 20.0 mL of the prescribed solution into a 500 mL conical flask”.
- Udsagn i Ph.EUR. ”1mL of sodium edetate is equivalent to 17.11 mg of $Al_2(SO_4)_3$” henføres til den mængde af EDTA, som er blevet kompleks bundet til Al^{3+}-ionerne)

Skridt	Handling inkl. reagenser og anvendt udstyr	Reagens	Funktion af reagens / handling
1	Afvej 0.500g aluminiumsulfat i en vejebåd på en analysevægt (differensafvejning) og overfør råvaren til en 500 mL Erlenmeyer kolbe.	Aluminiumssulfat	Analyt
2	Opløs råvaren i 20 mL demineraliseret vand afmålt med et måleglas.*	Demineraliseret vand	Opløsningsmiddel
3	Tilsæt 25.0 mL af 0.1 M natrium-EDTA opløsning til opløsningen af aluminiumsulfat afmålt med en fuldpipette (eller burette).	0.1 M natrium-EDTA	EDTA tilsættes i overskud for at undgå udfældning af aluminiumhydroxid
4	Tilsæt 10 mL af af en 1:1 opløsning af 155 g/L ammoniumacetat og 120 g/L eddikesyre afmålt med måleglas	1:1 opløsning af 155 g/L ammoniumacetat og 120 g/L eddikesyre	Buffer (pH ~ 4.76)
5	Kog opløsningen i 2 min og afkøl den til stuetemperatur	-	Sikre fuldstændig reaktion mellem EDTA og Al^{3+}-ionerne
6	Tilføj 50 mL ethanol afmålt med måleglas	Ethanol	Sikre opløseligheden af dithizon
7	Tilføj 3 mL af en ny fremstillet 0.25 g/L opløsning af dithizon i ethanol afmålt med måleglas	0.25 g/L opløsning af ditizon i ethanol	Metalionindikator
8	Titrer den overskydende mængde EDTA med 0.1 M zinksulfat indtil opløsningen ændrer farve fra grøn-blå til rød-violet. Til titreringen benyttes en burette.	0.1 M zinksulfat	Titrant