UNIVERSITY OF COPENHAGEN

DEPARTMENT OF PHARMACY

Improving Quality of Laboratory Learning at University Level (IQ-Lab): Project Description

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Table of Contents

Short Project Description

Students' work in laboratories is central to science education. In particular in educating pharmaceutical experts, as laboratory learning is essential for the strong focus on quality control and regulatory sciences. But despite the centrality of laboratory work, it is unclear what learning outcomes students gain from working in a laboratory. More knowledge is needed for improving the quality of laboratory teaching, and, in turn, the competences acquired by the pharmaceutical candidates. Since the overwhelming majority of educational research on laboratory learning concerns primary and secondary education, there is a clear need for substantial research on the role and efficacy of teaching activities in laboratories at university level. Indeed, laboratory work is bound to have a different role in higher education than in primary and secondary education.

The overall aim of this project is to provide teachers, researchers and curriculum designers with in-depth knowledge about

A. which competences students acquire from laboratory work,
B. how they best acquire these competences, and
C. how these competences are used and developed beyond laboratory courses.

As a means to this aim, the project pursues answers to three research questions:

RQ 1. How can laboratory-related competences in a university pharmaceutical education context be described and characterised?
RQ 2. Which factors influence pharmaceutical students' acquisition of laboratory-related competences, and how can such competences be assessed?
RQ 3. In which contexts and how are acquired laboratory-related competences activated and developed further at later stages in the pharmaceutical program?

The results of the project will inform practice and research within university science education. Specifically, the results will indicate good practices for teaching and learning of relevant competences in pharmaceutical programs. In-order to maximise its impact, the project will at the outset launch a network consisting of teachers, researchers and curriculum designers and engage these stakeholders continuously in order to make the research findings more operational. The success criteria for the project are:

A. **The project facilitates intra- and inter-institutional sharing of knowledge** by forming a national network about university laboratory learning comprised of university teachers, educational researchers and university curriculum designers/managers.
Indicators: consistent activities at seminars and via the online platform by network members.
B. **The project enriches teaching and learning in laboratories at other programs and institutions** by producing a catalogue of student competences to be gained from laboratory work as well as ideas and guidelines for how to assess student learning. The catalogue will be intended for use by teachers. The catalogue will involve concrete examples from the project and it will be published on a platform for stakeholders. *Indicators: uptake of project findings reported in the catalogue e.g. by members of the network; testimonials about usability of the project findings from network and advisory board members.*
C. **The project leads to an increased awareness of laboratory-related competences in the later stages of pharmaceutical program at UCPH** by engaging teaching staff in how to best use and help develop laboratory-related competences that students acquire during their 4th semester.

Indicators: tracked changes of teaching practices in courses at later stages in the program; testimonials from teaching staff.

D. **The project will substantially contribute to the state-of-the-art in several research fields** by reporting research findings in leading international peer-reviewed journals and at leading national and international conferences within science education, chemistry education, and higher education.
Indicators: submission of 8 papers and 3-5 conference presentations.

Project description

Problems addressed in the project

Laboratory work is an essential part of science education, because the laboratory setting ideally affords students' high-level content understanding while acquiring competences related to 'doing science' – a key skill-set for science practice (Hofstein 2017).

Students in biologically and chemically oriented fields, including the pharmaceutical sciences, spend a large amount of their weekly time in the lab, and laboratory teaching is an integrated and constitutive element of these programs. Most students like working in the lab, and among teachers there is a widespread recognition that lab work may provide students with important learning situations where the theories unfold in practice, and where students can acquire central competences and develop their scientific thinking and judgment.

But teaching in a laboratory is resource-consuming – in particular, within the field of analytical chemistry, where state-of the art equipment is expensive and costs for up to date teaching equipment are increasing. Thus, an analysis of the actual and potential learning outcomes of this type of teaching has become increasingly relevant.

There is an increasing tendency to substitute teaching in physical laboratories with teaching in virtual laboratories – e.g. in the form of simulation systems (Jong, Linn, Zacharia, 2013). It has been argued, that the instructional value of virtual labs compared to physical labs with respect to conceptual change is comparable or even superior, at least with respect to promoting conceptual change in students (Pyatt and Sims, 2012). However, there are strong reasons for seeing experiments and serendipitous findings as essential for the development of scientific knowledge, and the non-trivial interplay between empirical findings, theory and modelling (Pickering 1995, Cartwright 1999, Christiansen 2009). Further, the engagement with real measurement data cannot be adequately substituted by model based work (e.g. McCune and Hounsell 2005). Thus, while replacing exercises with simulations may be relevant in some cases, the justification of such action requires careful analysis of the actual and potential outcomes of laboratory learning.
For many teachers, it seems that the potentials of teaching in the laboratory are not always realised (see e.g. Petersen 2015, Wynns 2015). These intuitions resonate with science education research that for decades has identified challenges so perennial that they are still operative today (see Hofstein 2017, Nielsen 2017):

- Learning goals for laboratory work are often unclear (Tamir 1989)
- Students understanding of what is to be learned often differ from the teacher's conceptions of outcomes (Reid and Shah 2007)

- Students tend to "follow recipes" rather than focusing on the concepts underlying the exercises (Nakhleh 1994)
- Teachers and students alike tend to focus on "getting through" the exercises, rather than on student learning (Meester and Maskill 1995)
- Pre- and post-lab instructions are often insufficient for students to make sense of what is going on in the lab (Reid and Shah 2007)

In order to take steps towards improving the quality of future pharmaceutical candidates' competences, this project aims to generate knowledge about what constitutes high-quality laboratory teaching at *university* level. Specifically, the project aims to describe and delineate the laboratory-related competences students can gain, what the conditions for acquiring these competences are, and how the acquired competences are transferred and developed beyond the laboratory setting. The disciplinary context of the project is pharmaceutical analytical chemistry which is a core subject in discovery, development and quality control of drugs. Furthermore, pharmaceutical analytical chemistry is an applied discipline (in contrast to a pure discipline like physics) and draws on combined knowledge in a wide range of subjects. Thus, the gained knowledge on how to improve and assess learning outcome of laboratory teaching in this project will be of general interest for this wide range of fields within the biological and chemical subjects.

Project overview

The project is scheduled to run between January 1st 2019 and June 31st 2022 (3.5 years). The total work effort will amount to 189 person months over six work packages that are listed in Table 1. Figure 1 below shows the relation and flow between the work packages.

WP	WP Title	Start	End
1	Project Management	01.01.19	30.06.22
2	Describing potential laboratory-related competences	01.01.19	30.09.19
3	Strengthening the acquisition of laboratory-related competences	01.10.19	31.07.21
4	Tracking laboratory-related competences beyond the laboratory	01.10.19	31.07.21
5	Synthesis of Research Findings	01.08.21	30.06.22
6	Dissemination and Network Activities	01.01.19	30.06.22

Table 1: Overview of work packages

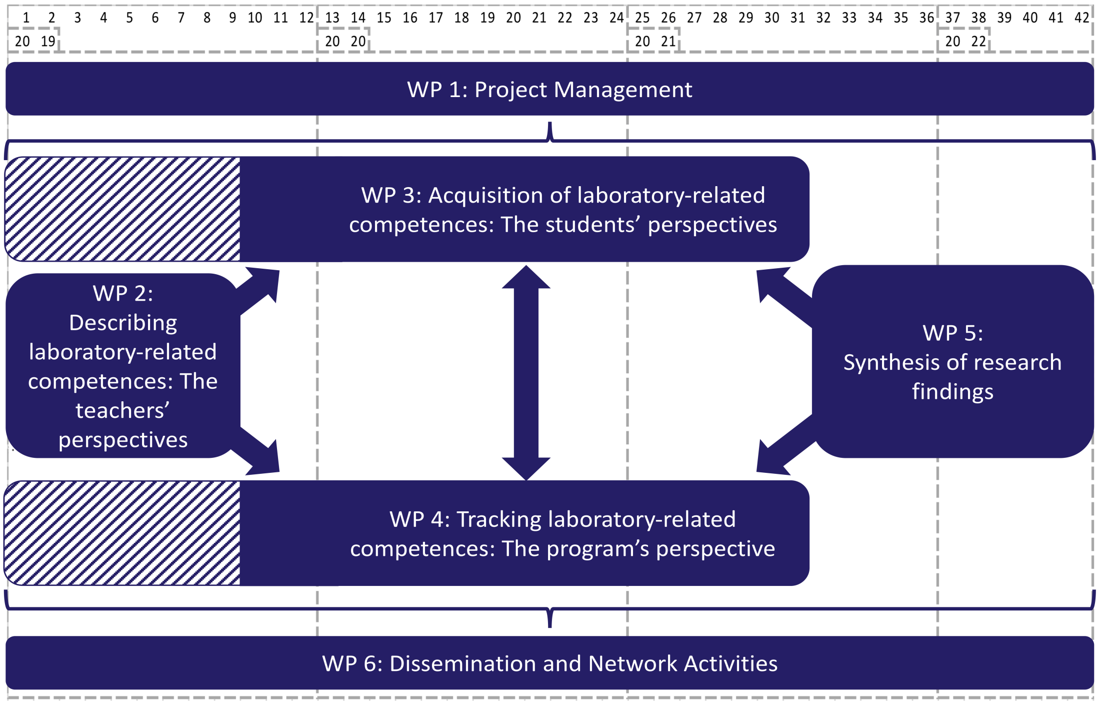

Figure 1: The relationship and flow of the WPs. The shaded areas in WP3 and WP4 signify that while these WPs start in month 10 of the project, the participants, in particular the two PhDs and the Associate Professor, will spend time during spring of 2019 (project months 1-9) with visiting the Pharmaceutical Analytical Chemistry course and getting familiar with the Pharmacy program as a whole, and thereby prepare for WP3 and WP4 during the work on WP2. The arrows indicate how the workpackges inform each other. WP3 and WP4 are not reliant on each other, but will certainly benefit from exchanges.

Organisation and project group

The project group constitutes a unique collaboration between the Department of Pharmacy (DP) and the Department of Science Education (DSE) at the University of Copenhagen (UCPH). The project group consists of:

- Project coordinator: Professor **Bente Gammelgaard (BG)**, DP, UCPH. Course responsible for the focus course *Pharmaceutical Analytical Chemistry* and a researcher in analytical chemistry.
- Associate Professor **Frederik Voetman Christiansen (FVC)** , DP & DSE, UCPH. Researcher in university science education.
- Associate Professor **Jan Alexis Nielsen (JAN)**, DSE, UCPH. Researcher in science education.
- Associate Professor (NN), DSE, UCPH. Researcher in science education with relevant methodological competences.
- PhD student 1 (NN)
- PhD student 2 (NN)
- Research assistant (NN), DP & DSE, UCPH.
- Administrative/communication aid (NN), DP & DSE, UCPH.
- Teaching assistant (NN)

The group members contribute with different expertise in an equal partnership. As course-responsible for the course Pharmaceutical Analytical Chemistry, BG serves as project coordinator. This means that the research activities in the project can begin immediately upon project start. The PhD students will be embedded in the teaching environment at DP as well as the didactic research environment at DSE and will thereby be able to draw on both chemical and educational knowledge bases.

A substantial part of the research in the project is performed through two PhD projects that form the basis of WP3 and WP4, respectively. Both PhD projects are collaboratively involved in WP2 and the initial part of WP5. An affiliated associated professor (NN) will conduct complementary research in WP2-5, and help ensure coherence across the different work packages.

During the teaching periods (every spring semester), a teaching assistant will work in close collaboration with BG and replace BG in teaching where the teaching is subject for investigations. Furthermore, the teaching assistant will assist the PhD students and affiliated professor in “familiarizing” with the pharmaceutical work in the lab and assist BG in implemention of minor interventions and administration of the course (e.g. changing course material etc).

In order to critically assess the progression of the project, a panel of stakeholders and experts will be formed. This panel will be asked to critically assess the project and provide feedback via digital communication during the entire project period. During the second network seminar (please refer to WP6), the panel will convene and discuss the progression and future aspects with the project group.

Coherence in the project

The project is led (through WP1) by a steering group consisting of BG, FVC and JAN. The steering group will be aided by the administrative assistant working in the project. Around 10 meetings a year for the entire staff in the project will help ensure that the WPs are aligned and coherent. (Frequencies of these meetings will undoubtedly vary from phase to phase in the project). While the steering group is formally in charge of securing the coherence between WPs, we envision that the Associate Professor will play an active and important role in ensuring this coherence, as the Associate Professor will be deeply involved in work packages 2-5. In particular, while the two PhD students will collaborate with and support eachother they will have individual and quite different projects in WP3 and WP4 respectively. The Associate Professor will be able to aid the steering group in making sure that the two WPs cross-pollinate.

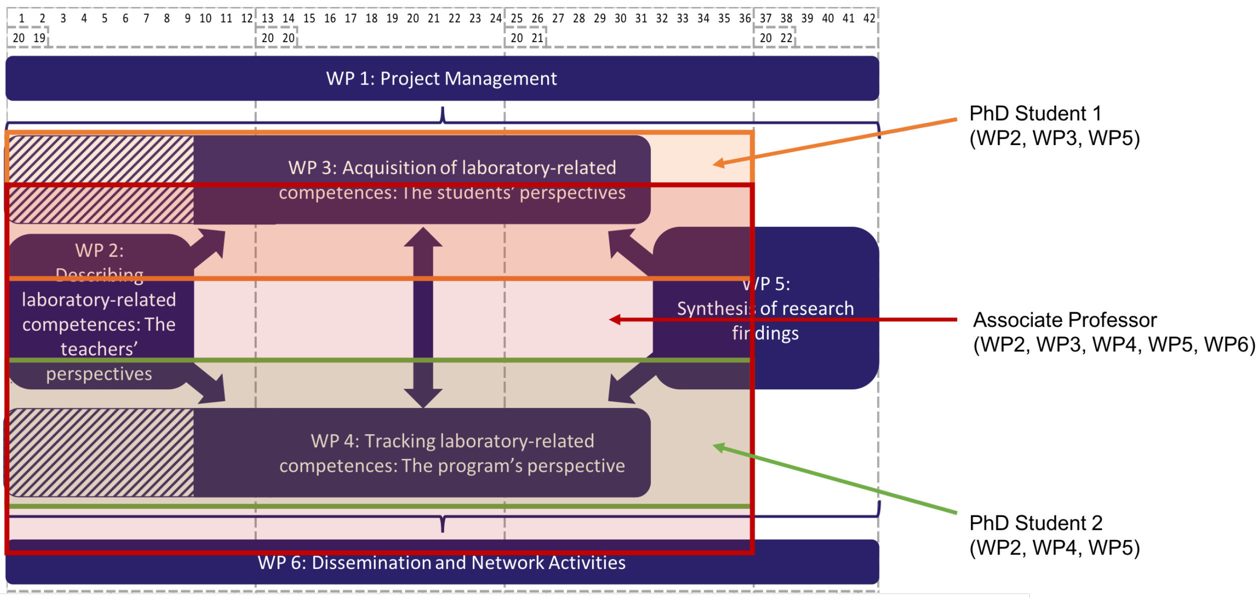

Figure 2: Overview of the project in terms of the responsibilities for the two PhD students and the Associate Professor. The two PhD students will also participate in WP6 (Dissemination and Network Activities) but they will not have a leading role like the Associate Professor and the Steering Group.

Context of the project

About 200 candidates are educated in pharmaceutical sciences at UCPH per year. A substantial number of these pursue careers in public and private research laboratories. A part of the vision of the Department of Pharmacy is to create state-of-the art laboratory facilities for curriculum teaching and for student projects. Thus, the Department of Pharmacy wishes to apply evidence-based laboratory teaching on modern equipment, encouraging students to engage in self-directed and responsible learning.

The course *Pharmaceutical Analytical Chemistry* will be the main locus of data collection for the project. The course is focused on chromatographic separation methods with mass spectrometric detection. By a partnership with *Agilent Technologies*, a private large vendor of instruments for analytical chemistry in life sciences, the Department of Pharmacy has been able to invest in modern equipment with the newest software platform.

The course is held every spring in the students' 4th semester. The purpose of the course is to make students able to choose a relevant analytical method for a given analytical question, control and modify experimental settings, perform the analysis, process the resulting data and evaluate the quality of the results. In short, the student should obtain a "driver's license" as a skilled analytical chemist needed for future analytical work within the curriculum and in his or her future career.

ECTS	**Bachelor courses - Compulsory**	
7.5	Drug Development	1.
7.5	Chemical Principles	1.
7.5	Pharmaceutical Physical Chemistry – Thermodynamics and Equilibrium	2.
7.5	Evaluation of Pharmaceutical Substances	2.
7.5	Pharmaceutical Physical Chemistry – Kinetics and Transport Phenomena	3.
7.5	Pharmaceutics I – Liquid and Semi-Solid Dosage Forms	4.
7.5	Pharmaceutical Analytical Chemistry	4.
7.5	Pharmaceutics II – Solid dosage Forms	5.
15	Bachelor's Project in Pharmacy	6.
	...	
30-60	Master's Thesis	9.-10.

Table 2: Courses including laboratory work in the Cand. Pharm. Curriculum taught at Pharmaschool**.** As is evident, the students already have extensive laboratory experience when they enroll in the Pharmaceutical Analytical Chemistry course. Teachers from the previous courses will be interviewed as part of WP2.

Theoretical framework of the project

As stated above, the project will investigate laboratory-related competences from three perspectives: (a) How these competences can be characterised and made operational for teaching and learning, (b) how they are acquired, and (c) how they develop beyond the setting of this particular course. These three perspectives on laboratory-related competences require individual theoretical approaches. These will be described in the description of WP2, WP3 and WP4, respectively.

Across the three perspectives on laboratory learning, the concept of *competences* is central for the project, and some basic considerations on the concept are needed in order to understand the ambition of the proposed research project. In the Danish context, important explorations of educational competences have been described in a number of reports financed by the ministry of education in the beginning of the millenium – pioneered by the formulation and elaboration of mathematical competences for all educational levels (Niss and Højgaard, 2011 (Danish version from 2002), followed by a report on science competence (Andersen et al, 2003; see also Busch et al., 2004). Niss and Højggaard defined a (mathematical) competence as the “well-informed readyness to act appropriately in situations involving a certain type of mathematical challenge” (Niss and Højgaard 2011, p. 49). In their view, a competence can be further described by its *degree of coverage* (aspects of its application)*,* its *radius of action* (contexts of its use) and its *technical level* (mastery of technical aspects of the competence). Thus, it is supposed that aspects of (mathematical) competences develop with time, as students progress through the educational system (Niss and Højgaard, 2011, pp. 72-74) along these different dimensions of the competences. The current projects seeks to identify competences related to university laboratory learning and to explore their development over time by considering in particular the modes of application of the competences and the contexts of their use (i.e. in particular the *coverage* and *radius of action* aspects of the competences). Another conception of the concept of competence (given by Marton et al. 2004), is that the acquisition of competences has a *specific* and a *general* aspect (see also Winsløw and Grønbæk 2003 for a similar idea). Teachers design learning activities for students to engage in, and these activities have a dual purpose. One the one hand students will need to engage in and learn about the specific content, skills and methods needed to complete specific exercises and tasks (for instance involving a specific separation method). Marton et al. (2004) call this specific part of the competence the *direct object of learning.* On the other hand, the very activity is designed with an overall aim for the student to acquire general skills and perspectives that they can employ in their subsequent study and future work-life. This is the *indirect object of learning.* However, what the students’ learn in the short and long term may not be strongly correlated to what the teachers had in mind. Marton et al. (2004) term the students awareness and experience in actual teaching situations the *enacted object of learning.* In the current project we will seek to explore the development of students laboratory related competences as the combination of *direct* and *indirect* objects designed by the teachers and curriculum developers, and the *enacted* objects of learning encountered by the students as they progress through their study program.

So what are the kinds of competences students may (potentially) obtain from engaging in work in the pharmaceutical laboratory? Reid and Shah (2007) provide four overall classes of competences or aims for learning in the chemical university laboratory (drawing upon previous work - Kirschner and Meester 1988, Johnstone et al. 2001, Carnduff and Reid 2003; see also George-Willams et al.., 2018):

- Skills relating to learning chemistry: E.g. trying out things, seeing theoretical concepts explored in practice.
- Practical skills: E.g. handling chemicals and equipment, master techniques etc.
- Scientific skills: E.g. observation, deduction, data interpretation
- General skills: E.g. team work, reporting, presenting, discussing, time management, problem solving (based on Reid and Shah, 2007).

The above list of competences is faily generic and potentially could be obtained in any science discipline (and replacing “chemistry” in the first bullet with e.g. “physics”, “biology” etc.). However, descriptions aiming more specifically at designating distinct *chemical outcomes* have also been made. Thus, Jospephsen (2003) suggests a pragmatic typology of distinctively chemical laboratory outcomes:

- **Synthesis**: To devise and control a chemical reaction to give an intended chemical **substance** [..]

- **Separation:** To isolate a particular **pure substance** or group of substances from a mixture
- **Detection:** To prove the presence of a given **chemical substance** or component is present in a sample.
- **Identification:** To demonstrate the identity/stochiometry of a particular **chemical substance** or a well-defined mixture of substances
- **Characterisation:** To determine a particular qualitative property of a pure **chemical substance**, a component, or a well-defined mixture of substances (Josephsen, 2003)

Both types of descriptions tell us something about the kinds of competences aimed at in chemical laboratory instruction; the list by Reid and Shah gives us an insight into the various types of generic competences which can be obtained and (presumably) employed in contexts beyond the chemical laboratory. The description given by Josephsen provides a perspective on competences which are uniquely chemical, but likewise generic and crucial in the development of chemical expertise.

Methods used in the project

Since the project seeks to explore laboratory-related competences from three different perspectives a variety of methods will be employed involving qualitative data from different sources. The primary types of data accumulated in the project are:

- Audio recordings of semistructured individual interviews with students enrolled in the course
- Video recordings of students' work in the laboratory
- Audio recordings of semistructured focus group interviews with faculty (teachers, course leaders and heads of study)
- Students' products in the course and in selected courses and projects after the fourth semester (thesis reports, oral presentations etc.)

The different approaches to data-collection and to data-analysis are outlined in detail in the ensuing work package descriptions.

Possible interventions and impact of the project

Overall, the project seeks to explore, clarify and substantiate the laboratory related competences in a university pharmacy program and explore their development longitudinally over time drawing upon both student and teacher perspectives. While the project is not conceived as an *action research project*, it is a clear ambition that the research project should influence the teaching activities in the short term as the project progresses, and, in the longer term, also course and program objectives. This will be accomplished in different ways:

- *Building mutual understanding in the group of teachers involved in lab related teaching.* In WP2, a large group of teachers and course responsibles will engage in focus group interviews about the specific laboratory-related competences aimed at in the *cand.pharm*. program. The focus group interviews will take as its starting point a literature-based characterization of skills and lab-related competences. In the research interviews, we will obviously not seek to push specific agendas unto the interviewees. But the focus group interview is a format which will allow the teachers to reflect upon their current practices, experience divergence of opinions and also reach consensus concerning objectives and goals (Bryman, 2012). In the *respondent validation* phase of WP2, the interviewed teachers will be confronted with the collected perspective developed by the research groups as a result of the expert validation. Thus, the project will include intervention by bringing increased focus and mutual understanding of objectives to the group of teachers responsible for the lab-related activities. Given that the focus group interviewees are primarily the course teams, these groups have a substantial leeway to make changes and adjustments in the teaching activities in the involved courses. Such changes could include e.g. adjustments of exercises and criteria for their assessment, for instance to focus more explicitly on specific competences or include other types of competences.

- *Learning from student interviews, actions and products.* In WP3, students will be interviewed about their experiences of congruence and central learning outcomes in the specific course Pharmaceutical Analytical Chemistry. Additionally, students' actions in the lab will be observed and analyzed in order to explore relations between student and artifacts, teachers and peers. These analyses will provide a unique insight into laboratory learning in the pharmaceutical labs in general and for the specific course in particular and will inform research-based interventions for learning environment design. Given that BG is course leader for the specific course, there is good reason to assume that many relevant changes and adjustments can be implemented within the time-frame of the project. We see it as a distinct strength of the project, that BG has course responsibility for the specific course in the long run as this will ensure a short path from research findings to changed teaching practices.
- *Longer term influence on the pharmacy program.* It is worth recognizing that changes to program stuctures, and even major changes to learning objectives and assessment schemes in a university program like the pharmacy program considered is a task that is not accomplished overnight. There are several reasons for this. One is the logistics involved – each year 240 students are enrolled in the pharmacy program with teaching conducted in 8 parallel classes. Thus, major changes will have to be considered very carefully to ensure their coherence and feasibility. Another point is the time-delay involved in major changes in objectives and assessment schemes for students (which is currently up to 2 years for administrative and legal reasons). Thus, while the research project may be instrumental in assisting study leadership and teachers towards relevant major changes of the program (e.g. clarification of progression in lab-related competences), it seems unlikely that larger changes can be implemented effect within the 3 ½ year timeframe of the program. However, it is the ambition in WP5 to provide research-based guidance on how to improve the practice of teaching laboratory related competences at the univeristy, and the most immediate target group for these suggestion will, of course, be the study board and teachers at PharmaSchool.
- *Influence on teaching practices outside of the specific program***.** It is the hope that the establishment of a national network for university laboratory learning and an electronic dissemination platform will contribute to inspiring teachers engaging in further studies of and interventions in university lab teaching (WP6). Furthermore, as FVC is course leader at the Higher Ed Teaching and Learning Programme (a joint programme for assistant professors and postdocs within Science and Health) the research findings may be used in this course, and lead to further development projects by course participants (see references IUTL 2015-18 for examples of such work).

Description of Work Packages

Work Package 1 – Project Management

Period: Project month 1 (01.01.19) to project month 42 (30.06.22)
WP-leader: BG

The objective of WP1 is to create and maintain a mutually beneficial environment for the research work in the project group, and to secure the overall administration of the project, as well as securing that each work package is in step with the other work packages.
Specifically, WP1 organises, prepares and facilitates regular meetings in the project group.

Work Package 2 - Describing laboratory-related competences: The teachers' perspective

Period: Project month 1 (01.01.19) to project month 9 (30.09.19)
WP-leader: JAN

The objective of WP2 is to answer *Research Question 1:*
How can laboratory-related competences in a university pharmaceutical education context be described and characterised?
This work is essential to secure a shared understanding of how to characterise pharmaceutical laboratory competences, which type of teaching and learning activities are conducive for their development, and how these competencies can be assessed is of central importance to WP3 and WP4.

Theoretical framework for WP2

A desktop analysis of laboratory-related learning objectives consists of extrapolating identified learning objectives from the literature and analysing relevant descriptions of relevant laboratory courses at university pharmaceutical programs. But such an analysis in itself will only provide a narrow understanding of what laboratory-related competences are relevant and to be aimed for in pharmaceutical programs. Nielsen, Tidemand & Dolin (2018) argue that a stated learning objective – such as being able to 'independently plan and execute a validation of an analysis method' (which is one competence objective of the course in Analytical Chemistry in focus) – is to some extent a *floating signifier*: The precise meaning of what it means for a student to have achieved this objective depends on the context and on the person who has to assess whether a student has achieved it. A core part of teaching (although this part is often tacit or implicit) is to make operational the set of learning objectives so as to be able to plan and carry out one's teaching and to assess whether students achieve the intended learing outcome. This process of *operationalisation* (Nielsen, Tidemand & Dolin, 2018) is an interpretative process through with a specific learning objective is fleshed out. The underlying notion of WP2 is the idea that a comprehensive understanding of any learning objective requires an investigation into how the learning objective is being operationalised for teaching and for assessment. Therefore a core of WP2 is an investigation into how relevant teachers at the Department of Pharmacy make operational laboratory-related competences as learning objectives for students, encompassing both the more general aspects of the competences and the specifically pharmaceutical aspects of these competences (see discussion of competence concepts above).

Methods used in WP2

In order to explore Research Question 1, this work package combines a desktop literature review with *expert group interviews* involving the teaching staff and teaching leadership in the Pharmacy program. This combination is needed since most of the existing literature pertains to primary and secondary school experimental work there is a need to adapt these findings to the specific university and the specific pharmaceutical sciences setting. Thus, this work package has three steps as depicted in Figure 3.

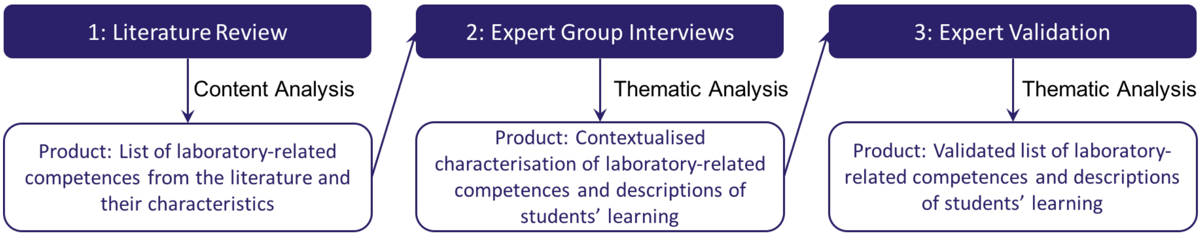

Figure 3: Phases of WP2

In the first step of this work package, we perform a literature review of relevant research publications vis-à-vis the identification and characterisation of skills and competences that are correlated to laboratory learning. The review procedure is a keyword search in relevant educational journals included in "Web of Science"'s "Social Science Citation Index" as well as in "'Education Resources Information Center" (ERIC) – e.g. in the period from 1990 to 2018. The keywords will include variations of the words 'learning', 'laboratory', 'skills', 'practical work' etc. Thus, the review will attempt to establish an overview of previously identified potential learning outcomes related to laboratory/practical work across disciplines and educational levels. The final list of keywords will be identified in project month 1 at a workshop for the entire research group in the project. The identified publications will then be read and all described potential learning outcomes will be extrapolated and categorised. The product of this first step will be a *thick description* of potential laboratory-related learning outcomes distributed in different categories and potentially different taxonomical levels (e.g. similar to the procedure in Elmeskov, Bruun & Nielsen, 2015).

The second step of this work package consists of a series of *systematizing expert interviews* (Bogner & Menz, 2009) – i.e. intrviews where the aim is to contextualise the findings from the literature review by tapping into the knowledge that to some extend is exclusively possessed by a group of experts (in this case, teachers and course responsibles). We envision 9 in-depth *group* interviews with the course teams for the individual courses (one for each laboratory course, see Table 2) with a total of 27-36 faculty members from the Department of Pharmacy (each course team has 3-4 members). For this project, group interviews are preferable to individual interviews since the group-setting usually provides "the opportunity to study the ways in which individuals collectively make sense of a phenomenon and construct meanings around it" (Bryman, 2012, p. 504). These interviews will be semi-structured (Kvale, 2008) and take outset in a group discussion activity about the product of the first step. Upon identifying the relevant potential learning outcomes from (and add other outcomes to) the list from the first step, the experts will be asked to discuss how these potential outcomes can be made, or are being made, operational for teaching and assessment in their practice. Further, the interviewees will be asked about how each identified laboratory-related learning outcome is typically acquired by students. Thus, the interviews will both address teachers' perspectives on potential learning-outcomes and learning processes in laboratory teaching. The interviews will be audiorecorded, transcribed and analysed using *inductive thematic analysis* (Braun & Clark, 2006). The end-product of the second step, is a list and describtion of laboratory-related learning outcomes that has been contexualised to the Pharmacy context.

The third step is a *respondent validation* of the product of the second step. Here the participating experts meet in the same groups as in the second step and discuss the specific formulation of the learning-outcomes and learning strategies. Here corrections can be elicited and a deeper understanding of the teachers' perspective is gained. The discussions will be audiorecorded, transcribed and also analysed using *inductive thematic analysis*. (As such, the second and third step resemble similar research approaches where new knowledge is generated by making research findings contextual through the eyes of practitioners, see e.g. Nielsen, 2015).

The overall product of work package 2 will thus be a research based overview of potential laboratory-related learning outcomes that has been highly contextualised in teaching practice in the Pharmacy program. This will serve as the common categorical framework for both WP3 and 4 and it will allow the investigation of students' competence development in the short- and long-term.

Work Package 3 – Acquisition of laboratory-related competences: The students' perspectives

Period: Project month 10 (01.10.19) to project month 31 (31.07.21)
WP-leader: FVC

WP3 focuses on *Research Question 2:*
Which factors influence pharmaceutical students' acquisition of laboratory-related competences, and how can such competences be assessed?
Specifically, the aim will be to explore dimensions of *congruence* for laboratory learning.

Context for WP3

The learning environment in the course has been designed with specific objectives in mind by the responsible teachers, and assessment has also been designed to assess these outcomes. About 200 students have to pass through the course every year, and the course organisation represents the typical set-up where students are divided into 8 classes, each followed by a teacher.

Theoretical framework for WP3

In recent years, university teaching in Denmark and elsewhere has undergone a transition from content oriented education to outcomes based education (Qualifications Framework, 2005, Biggs and Tang 2007). All courses are now being described in terms of learning objectives or competences that students should acquire in the course (Christiansen et al. 2015 p. 33–37). Moreover, the learning activities should support the acquisition of these goals, and the summative assessment of students should assess the same goals as far as possible. The concept of *constructive alignment* refers to this mutual interdependence of intended learning objectives, teaching and learning activities, and assessment (Biggs and Tang 2007). Obtaining constructive alignment is an ambition for teachers, but it is far from certain that the intended alignment is perceived as such by the students, and the concept is inadequate to capture all the central features of good student outcomes. Moreover, important dimensions of the learning environment are neglected by focussing on the elements of constructive alignment alone. Thus, Hounsell and Hounsell (2007) have suggested that high-quality learning and students' *way of thinking and practicing* is shaped by the *congruence* of a range of different dimensions. The dimensions of congruence to be considered are depicted in Figure 4.

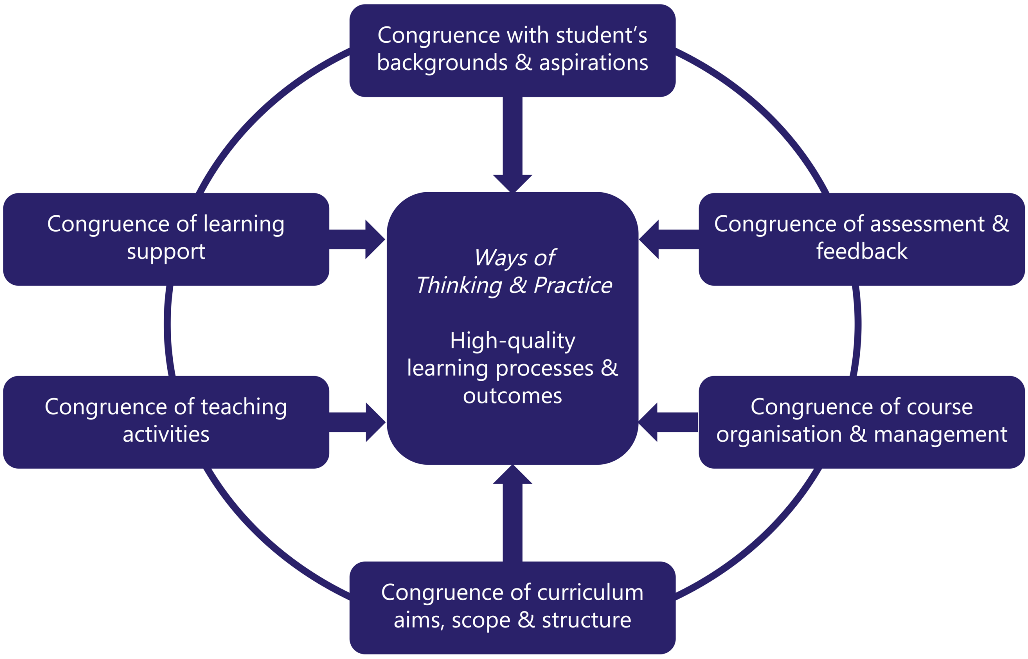

Figure 4: Congruence with teaching-learning environments (after Hounsell & Hounsell 2007)

Central to this theoretical framework is the idea of contextualised, disciplinary *ways of thinking and practicing* that students develop. Within this framework, McCune and Hounsell (2005) explored the students' ways of thinking and practicing within bioscience, based on three undergraduate theoretical bioscience courses. They found that students' engagement with experimental data was among the fundamental characteristics of the students' thinking and practicing, and students described how the engagement with data had been shaped by their learning in laboratory classes. However, while McCune and Hounsell (2005) identified the importance of the laboratory experience for the bioscience students' ways of thinking and practicing, they did not consider practical courses in their analysis. The present work package focuses specifically on how learning in the laboratory environment influences students' ways of thinking and practicing in the pharmaceutical sciences. Understanding the variation in students' conceptions of laboratory learning, and their approaches to learning in the specific pharmaceutical lab environment is thus the main focus of this work package. WP3 will consist of two separate perspectives on the question, where the first will be conducted by the PhD student 1, and the other by the employed associate professor.

Methods used in WP3

The First Perspective: Phenomenographic interview study

The first perspective in WP3 is a phenomenographic study with repeated individual interviews with students. The main source of data for WP3 will be analysis of semi-structured interviews with students, and analysis of student dialogue and action in the teaching session. This work will constitute a central part of the work for PhD student 1. The study will takes its theoretical starting point in the phenomenographical research tradition (Marton & Booth 1997, Entwistle, 1997), a well-established research in Higher Education research, but as yet not widely used in the study of laboratory learning (a recent exception is Burrows et al. 2017). In the phenomenographic study, the researcher seeks to explore qualitative variation in students' conceptions of the learning phenomenon under scrutiny, and seeks to elicit the categorical differences between the different types of conceptions held by the students, and possibly the relations between these categories (Richardson 1999). It is a recurrent finding in phenomenographic research that there is a limited number of qualitative different ways in which people experience phenomena, and that some conceptions are more comprehensive and powerful than others (Marton et al., 2004). Thus, for instance, Lybeck et al. (1988) explored students' understanding of the mole concept, and identified five qualitatively different general conceptions held by students, distinguished from each other by the understanding of the relation of the concept to other crucial concepts (e.g. amount, mass, number).

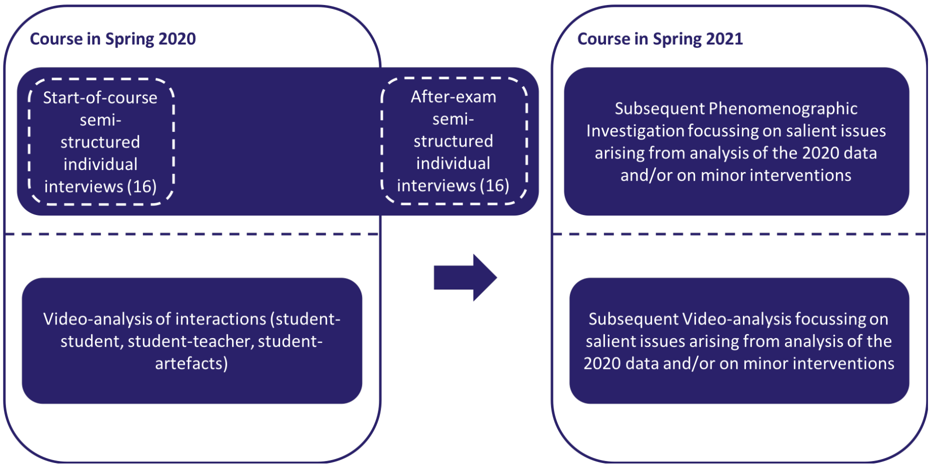

Figure 5: Schematic overview of the research methods in WP3.

The central source of student interview data and teaching observation will be the course offered in the spring of 2020, and teaching observations and curriculum analysis will be done in order to support the conduction of the individual interviews. Semi-structured interviews with students from four classes with around 16 students from the 8 classes will be conducted as they engage in pre-lab activities, laboratory work and post-lab activities. Each of the 16 students will be interviewed twice during the module, the first interview in the beginning of the course, and the second interview shortly after the exam in the course. The two interviews will have different main foci with respect to the dimensions of congruence described in Figure 5. For instance, in the first interview more focus will be laid on understanding students background and aspirations (including conception of the role of laboratory work for their learning), and in the second interview more focus will be laid on their conception on the assessment and feedback in the course for their learning. In both interviews the students' perspectives on the their central learning outcomes with respect to central concepts, methods and skills, and their approaches to learning in the course will be explored. The analysis will focus on the qualitative variation in students conceptions of learning in the lab, their approaches to learning and the acquired competences in the specific laboratory learning environment.

Through the individual semi-structured interviews it will be possible to describe an outcome space of ways of thinking and practicing in the laboratory setting, and the project will seek to identify central outcomes of the lab activities as conceived by the students. Moreover, it will be possible to identify central factors that are conducive to or inhibit student learning and outcomes by considering differences in individual conceptions between the first and second interviews (see Madsen et al., 2014 for considerations on changes in students conceptions through a course).

The methodology of using individual qualitative interviews to understand students approaches to learning and conceptions of phenomena is the paradigmatic phenomenographic metodology. The interviews can be seen as pieces of a puzzle which together form a picture of the qualitative variation in student conceptions of and approaches to learning. This method is well established and has proven its worth in a multitude of studies of university learning in the past four decades.

The Second Perspective: Video-analysis of Interactions in the Laboratory:
However, given the high complexity of the learning situation in the laboratory environment (Nakhleh et al., 2003), we wish to complement the methodology of qualitative individual interviews with observational studies of students' actual activity and relations to people and artifacts in the laboratory environment. In particular, there is a need to consider the relations of the student to the teachers, the fellow students, the laboratory equipment, the measurements, and the students' recording of events. It is our hypothesis, that these factors play crucial roles in laboratory learning, and it is reasonable to assume that the role of these factors may not be adequately represented through individual interviews with participants uncovered by the first perspective. How do these relations reconfigure the learning environment "on-the-fly", and shape the possibilities for learning and what is in focus as direct objects of learning (e.g. concepts, methods, skills, apparatus etc)? Thus, in parallel to the interview study outlined above, a study of students' interactions with the other students, with the teachers and with the artefacts will be conducted. This study will be conducted by the associate professor employed in the project.

This study will focus on a few specific laboratory exercises and follow a specific group of students in their laboratory activity through video and audio recording. The theoretical framework underlying the analysis will be *variation theory*, wherein experienced variation is seen as the central condition for learning, and can be seen as a learning theoretical superstructure to phenomenographical methodology (Marton and Booth, 1997). Among the central forms of variation discussed are four general patterns: *contrast, separation, generalization* and *fusion* (see Marton et al. 2004, Marton & Pang 2013). These (quite abstract) categories will be taken at the starting point for the relational analysis of the video and audio recording (as in Kobayashi et al., 2017), but will surely need to be defined with a higher degree of specification in order to characterize more closely the types of variation relevant to laboratory learning further. For instance, to abstract, to idealize and to average are three distinct types of generalisation (Harré, 1970) – all of which are used and have relevance in the lab context, and which should likely be distinguished.

Thus, the analysis will have specific focus on how students interactions with teachers, students and artefacts adds to or inhibits variation in the learning space. While using variation theory to explore the role of students, teachers and artifacts for learning opportunities in the pharmaceutical laboratory is a novelty, it is not without precedence in other domains. For instance, Berge (2011) used video recording of students problem solving in physics, employing variation theory to explore how group work (includinding discussions with the tutor) induce variation in physics problem solving (see Ingerman et al., 2009). Likewise, Kobayashi et al. (2017) have used video and audio recording of supervision meetings to study how variation in doctoral supervision (and the role of the supervisors) gives rise to opportunities of learning for the doctoral students within soil sciences. Eckerdal (2014) has proposed an analytical model for relating the theoretical concepts and practical programming activities based on variation theory.

Thus, the second study in work package 3 will supplement the phenomenographic interview study by exploring the students relations to the learning environment, but based on a theory of learning that is consistent with the perspective in the interview study. Taken together the two projects will provide a unique insight into *what* students learn in the pharmaceutical laboratory, and also on *how* and *by which means* they learn.

It will be possible to revisit and substantiate further the findings in WP3 in the spring of 2021 (and possibly even in 2022, but this goes beyond this WP and extends beyond the Associate Professors and PhD student 1's employment). It is foreseen that data can be gathered (in both perspectives) in 2021 on salient issues arising from the analysis of the data from 2020. Also, it is plausible that the spring 2020 study leads to small-scale research-based interventions for subsequent runs of the Pharmaceutical Analytical Chemistry course that would be interesting to follow. Large-scale interventions are difficult to envision because changes to the course description occur with a two year delay at UCPH; thus substantial interventions based on the analysis of the spring 2020 data will only realistically be set in motion in the spring of 2023. We do however envision that some of the resources needed in WP3 will involve data-collection and analysis beyond spring 2020. We envision that the Associate Professor will be the main party in performing these tasks.

Work Package 4 – Tracking laboratory-related competences beyond the laboratory

Period: Project month 10 (01.10.19) to project month 31 (31.07.21)
WP-leader: BG (run by PhD student 2)

WP4 focuses on *Research Question 3:*
In which contexts and how are acquired laboratory-related competences activated at later stages in a pharmaceutical program?
Specifically, this work package will follow the temporal development of students' laboratory-related competences into subsequent learning situations, where the competences are drawn upon. As such, the work package attempts to delineate the place and role of laboratory-related competences in a program-wide context – especially with respect to the conditions for transfer of laboratory-related competences.

Context for WP4

University programs are lengthy programs stretching from 3-5 years, even 8 years for students pursuing PhD degrees. For this reason, when students acquire new competencies or new sets of skills in an early course, it is the practicing of these skills and competences in subsequent courses and study units which will determine how they develop over time. There are a number of courses in the subsequent pharmacy program where such application of skills and competences are used in the 5th and 6th semester (Table 2). Thus, the work package will provide a much needed description of the temporal evolution of laboratory related competences in tertiary education. In addition, the project will be highlighting potentials for educational development of the Pharmacy program and inform teachers in both the Pharmaceutical Analytical Chemistry course and in the subsequent study units. The results may also be transferrable to similar elements of lab teaching in other natural science and life science environments.

Theoretical framework for WP4

WP4 will track the development of the laboratory-related competences identified in WP2 beyond the particular course in Pharmaceutical Analytical Chemistry. While the potential laboratory-related competences identified in WP2 are highly contextualised to the Pharmacy program, they will be abstract learning objectives – i.e. generalised statements of desired outcomes of learning. The fundamental theoretical vantage point of WP4 is that learning requires an explicit negotiation of enacted learning objects of the students and the direct and indirect learning objects designed by the teachers. This has been argued by e.g. Dysthe et al. (2008): only if learning objectives "are explicitly formulated as reifications of continuous negotiations and participation, they become part of a meaningful learning process […] Explicit criteria cannot be understood in isolation from the negotiation process" (p. 127).

In other words, a comprehensive understanding of laboratory-related learning can only be achieved by investigating the processes through which students and teachers 'negotiate the meaning' of laboratory-related competences. We place 'negotiation of meaning' in single quotes here because we hypothesise that this process often occurs implitcly and/or unplanned. To be sure, this 'negotiation' *can* happen explicitly and planned in a classroom setting – e.g. when a teacher directly states what he or she understands as a fulfilment of a specific learning objective. But most often, we hypothesise, that this negotiation occurs implicitly and in subtle ways – e.g. as more or less direct feedback to a part of a student's product. Finding traces of this 'negotiation' about laboratory-related competences would thus require a broad investigation of key points where teachers and students communicate about the students' learning vis-à-vis the competences in focus. As we describe below, this requires us to focus on the *students' products* including the assignment statements, the products that result from the students' interpretation of the tasks, and (crucially) the feedback given based on the products.

A further theoretical basis for WP4 is the notion of *threshold concepts.* It seems intuitive that there is a point in time where learning or development of a specific competence *really* takes hold – an episode where the "coin drops", so to speak. Meyer and Land (2003) have suggested, that disciplines have distinct *threshold concepts* that serve to break cognitive barriers and act as gateways for ways of thinking and practicing within the discipline (see also Meyer and Land 2005). Without developing a profound understanding of these threshold concepts, progress in the studies will be difficult for students (Loertscher et al., 2014). Threshold concepts have been identified in a long range of disciplines, including physics and law (Åkerlind, McKenzie and Trigwell, 2011), biology (Ross et al. 2010), and biochemistry (Loertscher et al. 2014). But these studies have not adequately considered the experimental dimension of the students' learning (e.g. Loertscher et al. 2014). Suggestions for threshold concepts of analytical chemistry have not been reported, but analytical chemistry is an interdisciplinary field and draws upon the general disciplines disciplines of chemistry, physical chemistry, physics and statistics. Hence, the threshold concepts of these disciplines can be hypothesized to be crucial for analytical chemistry as well (see Talanquer, 2014). The threshold concepts identified of chemistry, in particular *chemical equilibrium* is certainly very relevant for understanding separation methods, while concepts such as *light absorption* and *isotope abundance and distribution* may be hypothesized to be threshold concepts for understanding detection methods.

Laboratory learning includes aspects of knowing related to procedural and methodological skills, systematic parameter variation (Vincenti, 1993, pp. 159-166), understanding of relationship between data, theory and model, and embodied knowledge. These types of knowing are, in our view, crucially important for professional pharmaceutical practice, and there is reason to assume that these learning experiences are likewise transformational for students' learning processes and have profound importance on their ways of thinking and practicing over time. They comprise, we hypothesise, aspects of the students' *approaches to problem solving*, their *ways of working procedurally and methodologically* in the discipline, their way of *framing hypotheses*, and of *giving focus to evidence based knowledge*. Some of these aspects are likely to be strongly discipline specific while others are more general - for instance quality control and regulatory procedures are conceivably weighted higher in pharmaceutical ways of thinking and practicing than in the general sciences.

For lack of a better term we shall term these long-term and transformational outcomes of laboratory work *threshold methods and skills* (see Thomas et al. 2012 for a similar idea for computer science skills). Thus, the theoretical framework employed in this work package will rely on both the notion of threshold concept, and the generalised idea of threshold methods and skills, and pursue teachers' conceptions and students' competence development through the pharmacy program.

Methods used in WP4

WP2 provides a characterization of laboratory competences informed by the literature and by the teachers and curriculum developers in the pharmacy program. In WP3 the varation in students' laboratory learning outcomes will be explored by focusing on students' conceptions and approaches to learning, and the role played by peers, teachers and artefacts in a specific laboratory setting.

In order to answer Research Question 3, WP4 will focus on how laboratory competences come into play in the subseqent study units and how these competences develop over time as students progress in their study. The basis for the study will be an investigation of the points where there are possibilities for a 'negotiation of meaning' (see above) of laboratory-related competences identified in WP2, and will thus focus particularly on the products made by students in study units in the final part of the bachelor program. In the course of their study, students engage in independent work (individually or in groups) resulting in the various *products*, which are reasonably taken to demonstrate and develop the students' understanding of the subject matter and demonstrate their learning and competences. Thus, in order to understand the students' use and further development of laboratory related competences it is natural that the products produced by the students must be the starting point for the analysis.

These products take many different forms and vary in scope from smaller tasks to be completed for a specific teaching session, to products representing the outcome the of entire study unit (e.g. bachelor or master projects). The products may be written reports, project reports and assignments, oral presentations, peer-feedback, journal club presentation, posters etc.
The products are subjected to assessment in the form of either formative or summative assessment – or in some instances both types of assessment (Harlen & James, 1997). Roughly, the formative assessment is providing students with *feedback* on how they can develop further, while summative assessment is an assessment of the student's learning until a specific point in time (and typically without a strong focus on potentials for future development etc). Thus, the formative feedback on products (be it from teachers, peer-assessment or automated feedback) will be of particular interest in understanding the relationship between the enacted, direct and indirect learning objects. For this reason focus in the current project will be on the products made by students which are assessed primarily *formatively*.

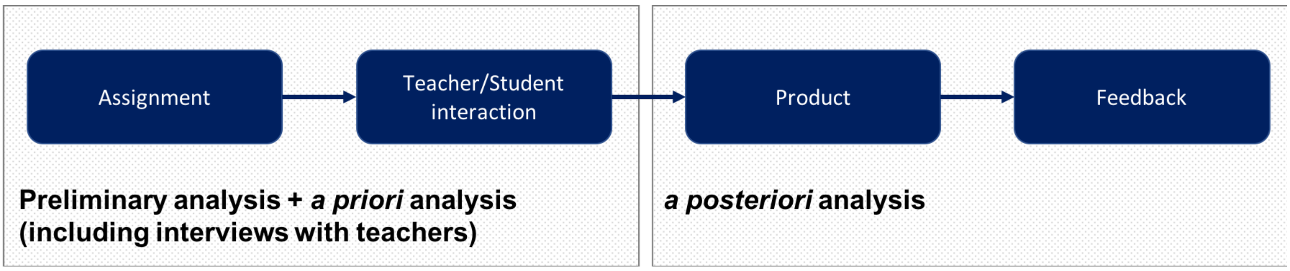

Figure 6: Overview of how the analysis of students products will be embedded in 'assignment-product-feedback-chains'. Each product is contextualized in a chain that 'begins' with an assignment, involves some student-teacher interaction and ends with feedback given to the student on the product.

The methodology employed is inspired by the so-called Didactical Engineering (DE) developed in the didactics of mathematics (Artigue, 2015, see also Artigue 2009, Brousseau 1997). The analysis of the products will have three overall steps: A preliminary analysis, an *a priori* analysis and an *a posteriori* analysis. The *preliminary* analysis will consist of an analysis of the design of the learning environment including an epistemological analysis of the nature of the assignment (including identifying potential threshold concepts or *epistemological obstacles* as they are called within this framework), the design of the instructions to the students, and the accompanying instructions from the teacher (if any). Specifically, the relationship between the assignment and description of lab-related competences obtained in WP2 will be considered. In the *a priori* analysis, specific research hypotheses about the specific learning situation are framed with a "generic and epistemic" student in mind (Artigue, 2015). As a part of this, the responsible teachers will be interviewed about the intentions with or conceptions of the assignment, and which competences the assignment intends to strengthen or develop, and its relation to laboratory related competences (WP2). In the *a posteriori* analysis, an analysis of students' actual work and the feedback provided to them (from teachers, peers or automated systems) will be made. The aim of the approach is to consider the relationship between the *a priori* hypotheses and the *a posteriori* analyses of data in order to inform the future didactical design of the task, including the role of the lab-related objectives.

This work package will follow the students' development of their laboratory related competences longitudinally in the 5th and 6th semesters, and include an identification of all formatively assessed assignments in those semesters, and a mapping of their relation to the list of comptences identified i WP2.

Over the course of time, student products are contextualized as a series of 'assignment-product-feedback-chains'. This provides the potential for longitudinal tracking of competence development in individual (groups of) students over a series of assignments. PhD Student 2 (in collaboration with the associate professor and the steering group) will perform this part of WP4.

In the spring semester of 2020, the associate professor will focus on the experimental competences employed by students in their master thesis work. This work will be based on Didactical Engineering analysis of selected students' initial and intermediate products (e.g. initial results, drafts) and the supervisors feedback on these products. This analysis will provide a "back curtain" for the threshold concepts, methods and skills and laboratory related competences used by the near-graduates, which can inform the observations of students in the 5th and 6th semesters. The analyses of student products will use a method similar to the one employed by Josephsen (2003), where student projects were assessed with respect to the presence or non-presence of specific types of experimental experience.

In the fall 2020 and spring of 2021, students from the classes that were followed in WP3 in the spring of 2020 will be observed and interviewed as they progress in their study toward the end of the bachelor degree. Focus will be in particular on the course in Pharmaceutics II (5th semester) and in their bachelor project work (6thsemester). Thus, taken together, the WP3 and WP4 will follow a cohort of students over three semesters in order to unfold and substantiate the development of laboratory-related competences over time.

The number of situations studied in the study of the formatively assessed products in the two semesters will depend on *which* products are chosen as objects of study, the nature of the *products* (e.g. written reports, presentations etc) and the nature of the *feedback* to students, and a thorough analysis of the different courses will be necessary in order to determine this precisely, by considering e.g. the relation to and the overall coverage (if possible) of the laboratory competences described in WP2. For illustrative purposes we will provide an example of such a formatively assessed product from the bachelor project.

The group-based bachelor project is initated with a planning phase where students are asked to employ litterature to devise an experimental protocol for theire experimental work, including an initial hypothesis, considerations on methods, safety and statistical considerations. A written description of this product exists, and a meeting is held with the supervisor where the expectations are clarified. The expectations for the product vary quite a bit because some students have longer time to prepare the products, because of the scheduling of the laboratory time – so while some groups have only a few days to prepare the product others have more than a week. After the report is delivered to the group's supervisor, a meeting is held where the group receives feedback on their plan. Thus, this session includes analysis of written material, and the first meeting with the supervisor clarifying the expectations, analysis of the groups' work and the subsequent feedback session. The preliminary analysis will depend on the specific topic chosen by the students, but would seek to frame the topic in the institutional context, curricular preconditions etc. The *a priori* analysis would establish hypothesis regarding relevant lab related outcomes (concerning mainly experimental hypotheses and *experiment design*) and the task and e.g. time available for completion of the task. The *a posteriori analysis* will analyse the hypotheses in light of the data, and elicit suggestions for the redesign of the learning environment.

Work Package 5 – Synthesis of Research Findings

Period: Project month 32 (01.08.21) to project month 42 (30.06.22)
WP-leader: FVC

In WP5, the project group – in particular the senior researchers – will synthesise and generalise the findings of the WP2, WP3 and WP4. The outcome of this work package will be *suggestions for how to improve the practice of teaching laboratory-related competences at university.* The primary recipients of these suggestions will be teachers, researchers and university curriculum designers/managers. The synthesis of the research findings involves identifying the themes that emerge from WP2, WP3 and WP4, and make these thematic findings *operational* for relevant stakeholders. It is the ambition of WP5 to provide research-based guidance on how to improve the practice of teaching laboratory related competences at the univeristy, and the most immediate target group for these suggestion will, of course, be the study board and teachers at PharmaSchool.

In order to improve the impact of the project, the work in WP5 is tightly connected to the work in WP6 (see below). Specifically, stakeholders within the by-now existing network will be engaged in order to determine (1) the most relevant target audiences for the projects' suggestions and (2) how to communicate the suggestions to these target audiences. It is foreseen that the primary target audiences are *already* part of the network and that they thus gain ownership of the suggestions for practice.

Work Package 6 – Dissemination and Network Activities

Period: Project month 1 (01.01.18) to project month 42 (30.06.22)
WP-leader: JAN

WP6 facilitates and organises the communication and dissemination of the project with the aim of maximising the projects' impact. The project seeks to have an impact that ensures improving the quality of teaching for laboratory learning. In order to this, the project involves and addresses three types of external stakeholders:

- University teachers
- Educational researchers
- University curriculum designers and managers

The research and teaching area in focus (higher education laboratory learning) is as yet not a well-established field of study. In the Danish context, many authors have
recently published papers and articles on how to improve aspects of laboratory learning, particularly in the series "Improving University Science Teaching and Learning" – an anthology of projects made by former participants in the Teaching and Learning in the Higher Education Programme at the University of

Copenhagen. See for instance contributions by Matthes; Kjær; Grosskinsky; Marzec in IUTL 2018, Kretchmann; Cremer; Østrup in IUTL 2017, Frandsen; Jongberg & Nielsen; Liesche; Sørensen; Lafleur; Petersen; Wynn; Miklos in IUTL 2015. While these papers and many others with them demonstrate, that the question of laboratory learning is considered pertinent and a central interest for many teachers, it must be taken into account that these papers are made by practicing teachers rather than educational researchers, and that the papers have all been made as assignments to fulfill the authors' certifcation as university teachers. Few of these authors have published more than one eduationally oriented paper and, indeed, almost no Danish authors have published substantially and consistently on university laboratory learning in the chemically oriented sciences within the past 15 years (one notable exeption being Jens Josephsen, Roskilde University).

When the project launches, the project group will form a network that includes researchers, university teachers and curriculum developers. It will be natural to start the network as a Special Interest Group (SIG) within the Danish Network for Educational Development in Higher Education (DUN). A number of SIGs have been established within the last couple of years, but no SIG concerning laboratory learning exists. The network will seek to attract interested scholars, teachers, consultants, and curriculum developers for joint meetings and activities, and will both help to inform the project, and serve as a means for disseminating the knowledge gained to Danish teachers, scholars and curriculum developers. At least six network seminars will be planned throughout the project period in order to consolidate the Danish Network, with the ambition to establish also international contacts and meetings (as has also been the development in some of the already established SIGs).

The project findings will also be continuously presented through journal articles and conferences as described in the work packages. Specific outlets will be chosen so as to communicate the findings to the different types of stakeholders. For example, the findings will be communicated at conferences that target (i) general science education researchers (ESERA), (ii) analytic chemistry education researchers (ECRICE), (iii) general education researchers (AERA), (iv) university education researchers, teachers and university curriculum designers/managers (DUN, ICED). Further, by dissemination in scientific journals with educational focus as well as chemical and pharmaceutical education focus, the research results will be mediated directly to analytical chemistry community.

In order to create a hub for communication, a digital platform for higher education laboratory learning will be launched in the beginning of the project. It will be updated continually throughout the project. The platform will enable the project group to communicate to a wider audience on a public part of the platform, as well as with the network members.

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