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Danish university faculty perspectives on student learning outcomes in the teaching laboratories of a pharmaceutical sciences education

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ABSTRACT
With the purpose of bridging research and practice, faculty teaching laboratory courses in pharmaceutical sciences at a research university in Denmark were interviewed about their perspectives on learning outcomes of laboratory work. Findings from a recent systematic review of learning outcomes associated with laboratory work at university level were used as a frame of reference and the outset for the discussions. University professors experienced in laboratory instruction were divided into focus groups to substantiate and relate the educational constructs extracted from the review to their own teaching experience. Thematic analysis was used to explore the professors’ experience on whether and how their students developed experimental competences, disciplinary learning, higher-order thinking skills and epistemic learning, generic competences, together with constructs from the affective domain. The analysis demonstrated that most constructs were relatable and observable in practice. Basic experimental competences and disciplinary learning were observed in the early stage of their education progressing towards higher-order thinking skills in
the bachelor’s and master’s projects. Some directions for future research and teachers’ professional development are proposed.

**KEYWORDS**
Laboratory Instruction, Upper-Division Undergraduate, First-Year Undergraduate/General, Second-Year Undergraduate, Chemical Education Research, Curriculum, Hands-on Learning/Manipulatives

**TABLE OF CONTENT GRAPHIC**

**INTRODUCTION**
Experimental work has been a part of post-secondary science curricula since the 19th century. As such, teaching in the laboratory is primarily devoted to learning how to do science\(^1,2\). In pharmaceutical sciences, laboratory instruction plays a key role in students’ motivation and competence development associated with the production, development, and quality control of drugs\(^3,4\). Nevertheless, the actual learning outcomes of this mode of science instruction have been debated. Major reviews of published empirical studies on laboratory education point to the lack of learning associated with school laboratory instruction\(^5\) and a need to clarify intended learning outcomes of university laboratory instruction\(^6\). However, previous reviews left a gap in comprehensive evidence for
student learning in university teaching laboratories, which was reiterated in a subsequent editorial by Bretz.

As the outset for a research project on improving the quality of laboratory learning at university level, we conducted a systematic review to describe and characterize learning in university chemistry laboratories, drawn from 355 peer-reviewed empirical studies. During the writing of the review, five preliminary categories of learning outcomes emerged, including experimental competences, conceptual learning, higher-order thinking skills, affective outcomes, and generic competences. The first category is defined as students’ ability to plan, design, and carry out a scientific inquiry efficiently and safely. Conceptual learning is defined here as understanding of the underlying accepted theories and methods in the experiment, whereas higher-order thinking skills refer to a host of critical, systemic, creative, and evaluative cognitive processes that lend themselves to more complex tasks such as problem solving and critical thinking. The fourth category is concerned with such psychological constructs as values, attitudes, beliefs, perceptions, emotions, interests, motivation, and the like. Finally, generic competences refer to knowledge and skills transferable across contexts and disciplines. These categories were synthesized from specific constructs reported in the reviewed primary studies. From a viewpoint of pharmaceutical education, they also represent potential competences related to chemistry laboratory work expected of pharmacy graduates. Although these categories and constructs are substantiated, they may not be self-evident in practice, and may even mean different to the practitioners in the context of their teaching laboratories.

The aim of this study is to contextualize the learning outcomes associated with experimental work drawn from the systematic review. Contextualization of systematic review findings is argued to be a crucial element in resolving the gap between research synthesis and practice. The study also aims to substantiate how instructors describe and characterize student learning outcomes in the laboratory, based on the categories summarized above. It is situated in the growing literature of faculty perspectives on student learning in the chemistry laboratory. To our knowledge, it is one of the first attempts at eliciting their views using research synthesis as a point of departure. In the previous studies conducted by Towns and colleagues, faculty goals for undergraduate laboratory instruction were substantiated, highlighting some common goals such as critical thinking skills and experimental design, but also nuanced differences between general chemistry, organic chemistry, and upper-
division laboratory courses\textsuperscript{15}. For example, there is more emphasis on uncertainty in measurement among those who teach in upper division, which may signify a stronger presence of inquiry type of instruction\textsuperscript{16-18}. In another study, meaningful learning theory was used as a lens through which faculty goals were analyzed\textsuperscript{14}. The study shows that the undergraduate chemistry laboratory provides avenues for learning across cognitive, affective, and psychomotor domains. While these studies are primarily concerned with faculty goals for laboratory instruction, or \textit{intended curriculum}\textsuperscript{2,19}, the present study is mainly aimed at student learning outcomes, or \textit{attained curriculum}\textsuperscript{20}. With instructional practice in mind, we aim to strive for constructive alignment in higher education\textsuperscript{21} in our own context.

Focus groups of university professors experienced in teaching laboratory courses in laboratories of pharmaceutical sciences, including laboratories of general, physical and analytical chemistry, pharmaceutics, and supervisors of bachelor's and master's projects were analyzed to address the following research questions:

(1) To what extent do the faculty teaching in the laboratory observe the learning outcomes synthesized through the systematic review?

(2) How do the faculty describe and characterize these learning outcomes?

(3) How do students develop the competences related to laboratory work in pharmaceutical education?

\textbf{THEORETICAL FRAMEWORK}

In this study, we espouse a theoretical framework of learning that concerns both students and instructors. Regarding the students, a multidimensional view of learning is adopted. Multidimensional learning is an emerging theory rooted in the learning sciences, particularly in the school of thought that departs from cognitivism\textsuperscript{2,22,23}. The theory embraces a more holistic perspective of the learners as an individual and a member of a larger social context\textsuperscript{24}. Scholars point to the critical role of affect, conation, and the social and cultural practices inherent in the subject disciplines, and the complexity of learning that stems from the interactions between those dimensions\textsuperscript{25,26}. In general chemistry curriculum, multidimensional learning is centered on the use of evidence to design a general chemistry curriculum that addresses core ideas, scientific and engineering practices, and cross-cutting concepts\textsuperscript{27}.
Regarding the instructors, we strive to use insights from research to help laboratory instructors reflect on their pedagogical beliefs, prior knowledge, and past experiences\textsuperscript{28}, by encouraging contextualization of research vocabularies in practice. Collaboration and engagement are key to this framing, as also argued by Herrington and Daubenmire in their work on chemistry teacher professional development\textsuperscript{29}, and it is reflected in the use of focus groups in this study, as elaborated in the next section. Therefore, we frame this study in professional learning theory\textsuperscript{30}, particularly the school of thought that acknowledges the complexity of learning\textsuperscript{31} as described above. This study was initially designed to elicit faculty perspectives of student learning outcomes. Throughout the course of our engagement with the local and national communities of practice in laboratory education at university level, partly by disseminating the findings from the review and this study, it became clear that it also serves as a way of fostering professional learning.

**METHODS**

**Context of the study**

The curriculum of the Bachelor of Pharmacy education constitutes 20 compulsory courses and two elective courses, all counting 7.5 ECTS (The European Credit Transfer and Accumulation System) each and the bachelor’s project counting 15 ECTS. Two departments joined in one study board are responsible for the education. The participants in the focus groups were permanently employed staff at the Department of Pharmacy responsible for the courses:

- 1\textsuperscript{st} year: Drug Development from Molecule to Man, Chemical Principles, Physical Chemistry (Thermodynamics and Equilibria), Evaluation of Pharmaceutical Substances
- 2\textsuperscript{nd} year: Physical Chemistry (Kinetics and Transport), Pharmaceutics (Liquid and Semi-solid Dosage Forms), Pharmaceutical Analytical Chemistry
- 3\textsuperscript{rd} year: Pharmaceutics (Solid Dosage Forms), Bachelor’s project in Pharmacy

These courses all involve laboratory work. The courses in pharmaceutics and the bachelor’s course are prerequisites for the competences built in the courses in physical and analytical chemistry. The part of the courses devoted to laboratory work is not specifically related to ECTS point, but the overall contribution of laboratory teaching of the bachelor’s education is about 30%. Apart from a few elective courses at master’s level, the laboratory education of the Master in Pharmacy occurs in the bachelor’s education.
Data collection

Thirty-one faculty at Department of Pharmacy, engaged in teaching as well as research, were recruited using purposeful sampling\textsuperscript{32}. We made sure that they represent a group of instructors with extensive experience of laboratory teaching at university level, which ranged from 5 to 30 years. In total, 8 professors, 21 associate professors, and 2 assistant professors participated in this study. We aimed at reasonably balanced representations of all teaching laboratories at the department, but concessions had to be made, due to limited schedule availability. Although they have been involved in various teaching laboratories, for the purpose of this study, they were asked to identify their main current or most recent laboratory teaching responsibilities, as shown in Table 1. Project supervision refers to their role as a supervisor of final-year research projects (locally termed as “bachelor’s project” and “master’s project”). Thus, all instructors are supervisors in master’s projects in their research field. All these instructors are involved in laboratory curriculum design and development, to various extents. Informed consent was obtained from all participants, and the study was approved by the Institutional Review Board (Case number 514-0278/21-5000).

Table 1. Research participants

<table>
<thead>
<tr>
<th>Pseudonym</th>
<th>Position</th>
<th>Main lab teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arden</td>
<td>Associate</td>
<td>Project supervision</td>
</tr>
<tr>
<td>Ashley</td>
<td>Associate</td>
<td>Physical chemistry</td>
</tr>
<tr>
<td>Aubrey</td>
<td>Associate</td>
<td>General chemistry</td>
</tr>
<tr>
<td>Carter</td>
<td>Associate</td>
<td>Analytical chemistry</td>
</tr>
<tr>
<td>Charlie</td>
<td>Associate</td>
<td>General chemistry</td>
</tr>
<tr>
<td>Clarke</td>
<td>Professor</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>Darby</td>
<td>Associate</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>Dawson</td>
<td>Associate</td>
<td>Physical chemistry</td>
</tr>
<tr>
<td>Ellis</td>
<td>Assistant</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>Finley</td>
<td>Associate</td>
<td>Analytical chemistry</td>
</tr>
<tr>
<td>Jessie</td>
<td>Professor</td>
<td>Analytical chemistry</td>
</tr>
<tr>
<td>Jordan</td>
<td>Professor</td>
<td>Project supervision</td>
</tr>
<tr>
<td>Jules</td>
<td>Associate</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>Kenny</td>
<td>Associate</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>Leslie</td>
<td>Associate</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>Morgan</td>
<td>Professor</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>Murphy</td>
<td>Professor</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>Quinn</td>
<td>Associate</td>
<td>Analytical chemistry</td>
</tr>
<tr>
<td>Reese</td>
<td>Professor</td>
<td>Physical chemistry</td>
</tr>
<tr>
<td>Riley</td>
<td>Associate</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>Robin</td>
<td>Associate</td>
<td>Analytical chemistry</td>
</tr>
<tr>
<td>Rory</td>
<td>Associate</td>
<td>General chemistry</td>
</tr>
<tr>
<td>Sacha</td>
<td>Assistant</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>Shannon</td>
<td>Associate</td>
<td>Physical chemistry</td>
</tr>
<tr>
<td>Skyler</td>
<td>Associate</td>
<td>Analytical chemistry</td>
</tr>
<tr>
<td>Spencer</td>
<td>Associate</td>
<td>Pharmaceutics</td>
</tr>
</tbody>
</table>
This qualitative study is centered on focus groups, as described by Wibeck and colleagues\textsuperscript{33}. We strive to shift the analytical focus from mere content analysis to an analysis of what the participants themselves are trying to understand and conceptualize\textsuperscript{33}. This methodological framing is aligned with the professional learning framework we have described above\textsuperscript{28,31}. Through discussions within small groups and plenums, participants were asked to make sense of the learning outcomes, by reflecting on their beliefs, knowledge, and experience.

The focus groups were held online on four different days during a lockdown period in Denmark. Four focus groups of a similar size were formed, representing the disciplines as shown in Table 2. Professors teaching laboratory courses in similar subjects were assigned to the same group.

\textbf{Table 2. Grouping}

<table>
<thead>
<tr>
<th>Group</th>
<th>Size</th>
<th>Lab representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>Physical &amp; general chemistry</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>Analytical chemistry</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>Pharmaceutics</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>Pharmaceutics</td>
</tr>
</tbody>
</table>

Each 1-hour session was structured as follows: Following a brief introduction, the group of 8 participants were divided into 4 small breakout groups (or 3 for Group 3), where they were asked to discuss a provisional list of learning outcomes generated from the systematic review (Table 3) that they had received by email a week before. The list was presented during the session on an online document platform that enabled collaborative editing. In each breakout group, they were asked to make sense of the constructs and contextualize them in their own teaching practice. Attention to details, exemplification, critical interpretation, refutation, and alteration of the list were encouraged. The list of constructs was presented in a Danish translation as well, but we purposefully did not elaborate on how each construct was defined, as the theoretical framework above suggests.

\textbf{Table 3. Potential learning outcomes of laboratory work}
<table>
<thead>
<tr>
<th>Categories of learning outcomes</th>
<th>Specific constructs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental competences</td>
<td>• Design experiments&lt;br&gt;• Carry out experiments&lt;br&gt;• Analyse data&lt;br&gt;• Understand lab procedures&lt;br&gt;• Apply Practical skills</td>
</tr>
<tr>
<td>Conceptual learning</td>
<td>• See connection between theory and practice&lt;br&gt;• Conceptual understanding</td>
</tr>
<tr>
<td>Higher-order thinking skills</td>
<td>• Critical thinking&lt;br&gt;• Problem solving&lt;br&gt;• Understanding the nature of science&lt;br&gt;• Metacognition</td>
</tr>
<tr>
<td>Affective outcomes</td>
<td>• Interest in lab or discipline&lt;br&gt;• Enjoyment of lab or discipline&lt;br&gt;• Motivation towards lab or discipline&lt;br&gt;• Confidence in lab or discipline&lt;br&gt;• Evolving a professional identity</td>
</tr>
<tr>
<td>Generic competences and skills</td>
<td>• Argumentation and reasoning skills&lt;br&gt;• Communication and writing skills&lt;br&gt;• Collaboration skills&lt;br&gt;• Take responsibility for own learning</td>
</tr>
</tbody>
</table>

Subsequently, the breakout groups convened in a plenary session, where each group presented the outcome of their discussions. A dialogic approach was used to gather different perspectives, by clarifying and elaborating prompts, but without evaluating statements from the researchers. The instructors were encouraged to validate the list. The focus group discussions and the plenary sessions were audio-recorded and transcribed verbatim (discussions in Danish were translated). Each session generated 3 to 4 recordings of breakout group discussions and 1 recording of a plenary session. In
total, our data consisted of around 12 hours of recording in both English and Danish. By the fourth session, data saturation was achieved, as similar comments across categories were mentioned.

**Data analysis**

The transcripts were analyzed with NVivo 12.6.0 using a six-phase thematic analysis as described by Braun and Clarke\(^{35}\), with some adjustments as follows. The first and second authors coded the data independently and met regularly to discuss about interpretation and gauge some degree of reliability. First, the material was read carefully with a high level of openness and sensitivity to data. Second, the structure of five categories of learning outcomes (Table 3) was used as initial codes in the analysis, but more codes were generated inductively, including sub-codes pertaining to a specific category, and thematic codes across the structure of the categories (See Table S1 in Supporting Information). In Braun & Clarke’s method, the codes are typically generated inductively from the participants’ perspectives. We combined deductive and inductive approaches to the coding process.

Third, the codes were subsequently collated into themes, with some merged while others further diverged. Fourth, the themes were revised accordingly as the results section took shape. Themes were defined and named in dialogue with other members of the research group. The researchers worked in collaboration to check the validity and trustworthiness of the data, through regular meetings, data sharing within the group, and iterative analyses, as recommended by other scholars in the field\(^{33,36,37}\).

The sixth author played a particularly crucial role in the validation of context, content, and data interpretation. Finally, a draft of report was compiled, presented, and discussed in a research group meeting, at a workshop for laboratory instructors and technicians at Department of Science Education, University of Copenhagen, and at Danish University Pedagogy Network Conference, Vejle, November 2021, which was further developed into the present paper.

**RESULTS**

The list of learning outcomes (Table 3) served as contextual information\(^{38}\) that facilitated discussions and guided a collective reflection on the instructor’s experience of teaching in the laboratory, by helping them to identify, categorize, and make sense of their observations in their own teaching contexts. The dialogic structure was largely open-ended to mediate the process of contextualization. We strive to present the results as a synthesis of how they make meaning of the
educational constructs drawn from the review, as much as possible ‘in their own words’, as argued by Creswell\textsuperscript{39}, to highlight the dialogic and constructivist approach that we use in this study.

**Experimental competences**

The instructors immediately recognize most of the constructs that fall under the category of experimental competences (carrying out experiments, analyzing data, understanding laboratory procedures, applying practical skills) as learning outcomes from the lab courses in the first years of the program, while they interpret the construct designing experiments as a more advanced learning outcome.

**Designing experiments**

Discussing the construct designing experiments, most of the instructors point to the bachelor’s project as a place where the students really get to practice and learn this. Conversely, some instructors highlight open elements in the introductory courses where the students get to train this competence, without getting through the entire design process. The reason why this learning outcome is less prevalent in the introductory lab courses is that the students need to be equipped with some experience as well as conceptual and experimental knowledge, before they are able to design experiments. Thus, several instructors perceive the ability to design experiments as somewhat different from the other points listed under the experimental competences, and some instructors would place this construct as a part of higher-order thinking skills. In the following, two instructors describe the competence needed to design an experiment:

- Jules: [The students] have to figure out, which kind of analytic method am I using? which settings do I apply? Which variables do I actually investigate, of the multitude we have? Then it is more than just an experimental competence. Because it needs a lot of thinking.

- Jordan: And a deep understanding of statistics, and the problem you are investigating, basically.

- Jules: Yea, so … design experiments might well be placed somewhere else, because it’s right. I mean the other points like carry out experiments, sounds very [much] like manually follow[ing] an instruction, and that’s what they are learning in the basic lab courses.
However, the instructors observe that when the students get to the bachelor’s project, they are able to meet the requirements of designing their own project, drawing on the experiences they have from the lab courses on the first years.

Carter: [E]ven though we might not train it as much, in the courses, on the first few semesters, the students, or many of the students, are actually able to design experiments themselves, when they come to the bachelor’s course. Somehow, they learn some skills, even though we may ... not have that, or specific focus on this element, in the initial courses.

**Basic experimental competences**

Most of the instructors address construct such as data production under a headline that could be basic experimental skills or learning to act and behave in a laboratory:

Jordan: We have the basic courses, where they have to learn ... all the tools of the trade. So they need to know a pipette ... [and] how they get data out of something. They need to make a linear regression on a standard curve. They need to understand they should clean up after themselves. Wear lab coat. Wear glasses. ... And that would be the basics, which they are taught ... and that is of course really necessary, ... that we can put them into a lab, and they can handle themselves.

Pipetting skills is a frequently used example among the interviewees of basic but necessary experimental skills that the students acquire through a lot of training in the early. Some instructors provide more examples of practical skills like measuring, weighing, and changing the column in an HPLC instrument. Several instructors also include knowledge of general behavior and basic safety procedures as a core in basic experimental knowledge.

Instructors distinguish between carrying out experiments and applying practical skills. Discussion on understanding lab procedures led to a discussion on distinguishing between simple execution of an experiment vs. the understanding of the theory behind the experiment, and some remark that the competence of understanding is less prevalent than practical skills as learning outcome.

Interestingly, the instructors add learning outcomes to our list of experimental competences. Several instructors mention the ability to make laboratory observations as a construct that pertains
under the basic experimental skills. In the following excerpt, two instructors discuss how accurate measurements and observation are basic skills that students develop in the introductory courses.

Reese: Of course, they have to learn how to weigh stuff, and they have to learn to observe if the substances actually dissolve. They have to [learn] how to make measurements and determinations, and also how difficult it actually is. [They have to] learn to observe what is going on right in front of their nose.

Aubrey: Yes, it is all these things, right. I have long discussions with my students, when they suddenly realize that they have forgotten to note the color of their solution to begin with – and then.. oh, was that important!

One of the instructors shares a typical experience from their lab teaching where students realize the importance of noticing the color of a solution. Fine-tuning an awareness on what is important to notice and what does not need attention is an experimental competence developed through practice.

One group also refer to the practical experience students get from making mistakes in lab. As an example, they mention a student using tap water instead of demineralized water when preparing a mobile phase for a chromatographic experiment. Experiences like this can translate into practical skills.

Critical evaluation of data and results

From discussion of the construct analyzing data, an additional learning outcome emerged, described as ‘a sense of’ or ‘a feel for data’, originating from working extensively with data generation by multiple measurements. This includes ‘a feel for variability’ or ‘a sense of variation’ – e.g. variations owing to equipment imprecision or human actions in the lab. According to the instructors, this experience is an important prerequisite for critical evaluation of data and results produced by themselves or others. They consider this competence of critical evaluation fundamental for pharmacists, even though some of them will never go back to the lab after they graduated.

Reese: I would like … to emphasize the ability that our candidates get, to evaluate data and results, because most of them will never get into the lab again, but most of them will have to evaluate data, that are generated in the lab. … In order to do that, you need to have done practical work yourself, and it doesn’t really matter whether it’s a pH meter, or a spectrophotometer, that you have used, and it’s different types of data,
that you are evaluating. So, in order to get a feel for variability and so on, you need to do lab work.

The students develop this competence from working with real data. More instructors emphasize the importance of making mistakes or for other reasons observe an imperfect fit between theory and data. Some of the instructors elaborate on how this misfit stimulates the students to critical reflection on data collection and possible sources of error, in contrast to working with perfect data, where they obtain a perfect fit and can proceed without reflecting further on data production. Thus, the experiences from working with real data serves as an important prerequisite for critical judgement of data and is obviously a competence the students develop in the laboratory.

Quinn: Well, I think it's important. Once in a while you get poor results, and it's important to talk about it. Ok, what can have gone wrong here? You need to adopt a critical approach to your own work, and a critical approach to the instruments you are using, or the methods you use. And in that case, I hope that running experiments, you ... come across the real world in a way that you don't see in a [theory] book where everything works ideally. And that this leads to a more critical approach to the results you can read about in articles.

Conceptual learning and theory-practice connection
To make connection between theory and practice is in most instructor’s opinion a crucial part of successful laboratory teaching. They mention that students have different ways of learning, and some students finds it easier to understand theoretical concepts through practical work. It helps ‘memorizing’ and makes abstract concepts more concrete and tangible, and thereby more accessible for the students to understand. However, learning theory through practical work requires the students to ‘take ownership’ instead of just following the instructions absent-mindedly ‘like a robot’.

Nevertheless, the students often find it very challenging to connect the theory behind the experiments while being in the lab.

One of the instructors describe how they experience a ‘gap between theory and practice in the student’s head’:

Jordan: [T]here is often a huge gap, between theory and practice in the student’s head.
That's my feeling at least. They know a lot of words ... from the textbook. But they
don’t really … understand them fully. [W]hen they work with them, they have to understand … what all the strange words in the lab protocol and … the textbook actually mean. … I’ve experienced a lot of … aha moments from students when they are in the lab. Investigating something connected to a theory, and then suddenly understands … why they are doing the things and what the theory is.

The students know some terminology and theoretical concepts from the textbooks and the lab manuals, but the deeper understanding and connection between theory and practice demands supervision by the instructor to make this connection:

Leslie: It's important to have supervisors or instructors in the lab that support and remind them of this connection, [of what] they learned in the theoretical part.

**Competences related to higher-order thinking skills**

Although some students already develop higher-order thinking skills in the first years, the majority develop this competence during their bachelor’s scientific project, which carries through to their master’s degree. As students progress through their pharmacy education, they become more independent problem solvers. Quite a few of the instructors concede that the more prescribed first year laboratory courses do not really afford the students much scope for developing their higher-order cognition.

Of the constructs related to higher-order thinking (critical thinking, problem solving, understanding nature of science, metacognition), instructors’ perspectives on students’ higher-order thinking skills centered mainly on problem solving in the laboratory. This is often contextualized as an ability to troubleshoot, when students need to diagnose a problem and determine a solution strategy. The importance of the instructor as a coach in providing guidance or more assertive intervention is emphasized.

In general, laboratory instructors agree that critical thinking in the laboratory is closely related to making sense of the data that students generate from the experiment. Encountering ‘bad raw data’ or making mistakes requires that students revisit methods and instruments and reflect on the reason. This stimulates students’ critical assessment of the validity of the data and nurtures critical thinking. It may also foster reflections on the constraints of ‘real world’ experiments in relation to the idealized scenario in the books they read.
With regards to the role of instructors in helping students make sense of the data, an instructor asserts:

Tyler: You keep on challenging them during their master’s project. Ask questions ... They are on their own, so they have to solve it themselves. That’s where they really develop this critical thinking. So, I don’t think we should be so worried that they are not so critical during the first years. But later on, it’s important.

**Understanding the nature of science and metacognition**

To the participating instructors, the constructs understanding the nature of science and metacognition seem to be not as relatable and they do not necessarily regard these skills as essential in the lower-division pharmaceutical science. Few instructors address the construct metacognition. Some interpret this construct as generic or transferrable skills and some are not sure what metacognition means. Some instructors mention that students develop metacognitive skills in the laboratory, but those who teach the first-year courses are apprehensive about such evidence. A short definition presented to the instructors may have helped the instructors relate to this construct.

It is noteworthy that laboratory instructors also seem to have different understandings of the nature of science. Some refer to inductive vs deductive approach to empirical data, whereas others refer to ‘[big] philosophical questions’ and ‘uncertainties tied to experimental results’. One example was how ‘complicated results’ generated from an experiment reflects the processes of science for students to think about. The discrepancy between experimental values and ‘theoretical results’ deduced from established scientific knowledge is regarded as an opportunity for learning about science.

Accordingly, the instructors acknowledge the importance of scientific methods in making pivotal decisions pertaining to daily lives and societal issues, as an instructor intimates:

Shannon: I think especially nowadays where people are questioning data, bringing up [own] opinion. I think it’s extremely important, that the background message in all our education, is [that] ... the scientific method is the light to follow’.

On that note, another instructor provides a nuance to the notion of scientific method:

Leslie: [T]hey have to learn these different methodologies, and the uncertainties ... bound to whatever type of measurement. Because ... if they are taught properly ..., if you
want to learn this concept, what can actually be measured in the lab? And then you
... learn what method you can use to analyze something, or to try to understand it,
and if you get the right understanding of what this method can do, and what the
results mean. Then you would get a better understanding of science in general.

However, in their experience of teaching laboratory courses, understanding the nature of science
may not be self-evident in experimental work, as one instructor describes, ‘... it's not necessarily
something they learn in a laboratory, it's something [they] learn when you’re talking to them’. Also,
most instructors agree that the epistemic domain of learning, as an insight into knowledge production
and evaluation, may be more evident in the scientific research project, particularly at master’s level,
where students get to be immersed in actual research. The following illustrates how a professor gets
an insight on students’ epistemic learning from discussions on the veracity of scientific knowledge in
the laboratory. In doing so, he acknowledges a lack of focus on this domain.

Aubrey: I've got some master’s students, working on a topic, where I know that there is a
 lot of faulty research around. So, I discussed with them why. I confidently claimed,
... that this is wrong. But then you get these interesting discussions, where they ask.
“But this is published, and there are so many papers. How can that be? I mean, how
can this be so obviously wrong and still be out there in the scientific literature?” So,
they understand that ... [t]here is so much wrong in the scientific literature ... [W]e ... 
have perhaps too little focus on the nature of science, in the sense that a lot of the
science that we do, is wrong. And then there are the things that are just plainly
wrong and should never have been part of the scientific literature.

Affective outcomes of laboratory work
The affective domain is often associated with the question of how students experience learning, as
opposed to what they learn. While constructs such as interest and attitudes are relatable to the
instructors, the affective domain of learning in the laboratory is not necessarily a familiar term. To
ensure validity, the category was described by several learning constructs substantiated in the
literature (interest, enjoyment, motivation, confidence). Our data may supply evidence for the affective
value of laboratory work, by students’ positive experiences of laboratory work that carry through the
entire bachelor’s and master’s programs, as an instructor reflects:
Ellis: [I]f we look at the ... kind of master’s projects that students seek, there are not many
that would like to do a theoretical project. Of course, we have the whole Social
Pharmacy Section who covers that. But ... I have never supervised a theoretical
project ... [T]hey want to get into the lab, when they get to that part. And that must
be also based on their positive experiences.

Some of these positive affective experiences were observed during a particular laboratory exercise
where students have ‘fun’ by changing a ‘small variable’ and testing it so many times that the
instructor has to stop them. The instructors also observe elements of confidence and evolving
professional identity in how the possibilities of working with state-of-the-art facilities in their teaching
laboratory provide students with a range of technical skills and help them develop a professional
identity as future pharmacists. Indeed, it is from these experiences early on in their program that
students begin to envisage the kind of career or further education they wish to pursue. However, it
should be noticed that the interviewees are all instructors in lab courses and would not be approached
by students who prefer theoretical projects.

Motivation seems to be the most prevalent affective construct instructors can relate to. They think
that motivation is at the highest when the experiments are well designed, varied, and relevant to
pharmaceutics education and future career. They also emphasize the importance of understanding the
theory underlying an experiment to keep motivation high. In terms of competence development, the
affective domain of learning in the laboratory also develops over time. This is for example
substantiated with a professor’s observation of bachelor’s vs PhD students’ attitudes towards
laboratory work when they make mistakes, exemplified by a student being annoyed when making a
mistake in producing a mobile phase in an early course, compared to making the same mistake during
the master project, inducing problem solving and a subsequent feeling of understanding and
confidence.

It is also noteworthy that instructors assign a higher affective value on more open inquiry
experiments, in which the outcomes are unknown, as opposed to more structured, verification
laboratory work. They describe that open-ended inquiry enhances students’ affective learning by
providing opportunities for experiencing the ‘thrill of doing science’ and identifying ‘scientific
preferences’. An instructor reflects on the experience of students in the bachelor project:
Robin: They have total ownership. And again, depending on their competence level, some of them get very far, and get really engaged in it, so... that's because it's completely open ended, and they have to design and characterize two drug products. And that gives them kind of a synthesis, of all they have used, learned early in the study.

Generic competences

The professors can relate to all of the generic competences associated with experimental work, particularly collaboration skills, which they perceive to be central in Danish education. These skills are regarded as self-evident, due to the way laboratory courses are structured. Discussions centered on how the group dynamic influences student learning, especially when the group population is diverse. An instructor exemplifies how it unfolds in an international group, where different cultural and pedagogical backgrounds keep the students from working together effectively.

Nevertheless, negotiating differences in such a diverse context are also viewed as a potential for learning about social and interpersonal skills as well as work ethics. Several instructors also find that reasoning and argumentation are essential outcomes related to generic competences, as students develop these skills through report writing and supervision sessions with their respective advisors. However, they are not specifically taught in the laboratory. In its current state, laboratory work affords only ‘top, highly motivated students’ the opportunity to develop argumentation and reasoning skills.

Writing and communication are also regarded as intended learning outcomes. However, a number of professors concede that more feedback could be given to ensure competence development in writing.

DISCUSSION

In this section, we will discuss these results according to the formulated research questions.

From empirical constructs to reflective practice

Laboratory courses constitute about 30% of the Danish pharmaceutical sciences education. Due to their central role, it is important for instructors and curriculum designers to use insights from research to inform practice. Our first research question is aligned with such argument. We aim to address ‘To what extent do the faculty teaching in the laboratory observe the learning outcomes synthesized through the systematic review?’ Results from the thematic analysis reveal that the faculty could relate to the evidence for learning substantiated in the review and observed some of the learning outcomes. They engaged with all categories, contextualized them in their extended teaching experience, and made amends where relevant and necessary. Evidently, experimental competences
were central to their discussions and, as reported here, they differentiated the construct in two categories: basic and advanced competences. The former refers to understanding of laboratory procedures and performances of various laboratory techniques, safety awareness, as well as basic data-related skills, whereas the latter refers to experiment design competence. The conceptualization of laboratory learning in the initial review was then contested when some of them suggested that experiment design belonged in the other category, *i.e.* higher-order thinking skills. This is debatable, but some laboratory education scholars indeed acknowledge the central role of higher-order cognition in experiment design\(^{40,41}\). Students need to incorporate a lot more critical and inquiry thinking in designing an experiment, compared to performing the experiment itself, which mirrors Bruck and Towns’s findings\(^{15}\). In their study, experimental design is identified as one of the common goals of laboratory instruction, on par with critical thinking, particularly among successful grant writers.

Some of the educational constructs may not lend themselves to a clear interpretation, such as ‘metacognition’ and ‘understanding of the nature of science’. This makes a case for better transposition of research vernacular into a language closer to practice. It also necessitates further explication for practitioners interested in evaluating student learning in this area. For instance, one of the original primary studies in the systematic review\(^ {42}\) provides some insights into how the construct metacognition has been operationalized, by looking into students’ engagement and reflection.

Metacognition is particularly important because of the high level of autonomy expected of students while they navigate in the complex learning environment of the laboratory.

Instructors’ reflection as described in this study is an example of the third layer of curriculum representation\(^ {20}\), *i.e.* the attained level (learning outcomes), in contrast to the first layer representing the intended level. As the instructors reflect on practice, guided by insight from research, they develop their pedagogical knowledge, in both conceptual and epistemological lines\(^ {43}\). Thus, instructors’ reflections in groups could lay a foundation for their professional development in laboratory pedagogy, and researchers can play a strategic role in promoting shared meaning and negotiating differences.

**Instructors’ characterization of learning in the laboratory**

The second research question concerns ‘*How do the faculty describe and characterize these learning outcomes?*’ In the instructors’ perspective, learning in the laboratory indeed encompasses several dimensions. Viewed across the five initial categories (see Table 3), there seems to be an
indication that deeper learning can be achieved mainly through open investigation. However, the
instructors also find that there is still a place for more prescribed experiments, although they all
refrained from using the term ‘cookbook approach’. They describe how learning basic skills in the lab,
such as observation skills and basic data analysis, are required to develop more advanced skills, such
as critical thinking. Such importance is also asserted by the faculty in Bretz and colleagues’ study,
both acknowledged researchers and those who focus more on teaching. Thus, learning in the
laboratory can be mapped across time in terms of increasing levels of inquiry and higher-order
cognition, in which students’ autonomy in conducting experimental work is a key characteristic.

Although not made explicit, the epistemic dimension of learning in the laboratory seems to
permeate the discussions among the faculty in our study, especially regarding critical evaluation of
data, understanding of the nature of science through instructor-student dialogues, and
argumentation. Proxies for epistemic learning in the laboratory were expressed by the faculty, such as
‘awareness of scientific method’ during laboratory work and dealing with ‘uncertainties of
measurements’. The latter is also identified in the previous work mentioned above, which is
particularly crucial in physical chemistry, where propagation of error calculations has to be
considered. Indeed, more focused investigation on this dimension is needed to elicit more specific
characterization of learning.

Epistemic practices are supposedly inherent in experimental work, including in the laboratory
of pharmaceutical sciences. In some cases, instructors only need to make this element more
explicit through conversations and argumentation. Research on argumentation is an established line
of inquiry. Accordingly, argumentation has an important role in experimental work, by which
students are actively engaged in critical discussions of methods, data analysis, and interpretation.

Competence development through laboratory work

The third research question is ‘How do students develop the competences related to laboratory work
in pharmaceutical education?’ In terms of experimental competences, students acquire basic skills in
introductory courses, after which they develop more advanced experimental design competence during
the following courses. This can be observed during the scientific project towards the end of their
bachelor’s degree. The lab instructors emphasized the importance of working with ‘real data’ that
students generate themselves, for them to develop beyond the acquisition of basic laboratory
techniques. Being present in the laboratory and generating own data are very crucial and indeed constitute the cornerstone of laboratory education\textsuperscript{55}.

Our results also indicate that experimental competences develop in synergy with other categories of learning outcomes, particularly higher-order cognition, epistemic understanding, and the affective domain. This synergistic development of various competences as perceived by the professors in our study mirrors that of Bretz and colleagues\textsuperscript{56}. In their study, these competences are conceptualized in terms of cognitive, affective, and psychomotor learning goals. In contrast, their analysis reveals that the presence of affective goals set by the laboratory instructors fades away in the upper-division laboratories (3\textsuperscript{rd} and 4\textsuperscript{th} year), while our study indicates that the affective learning outcomes develop throughout the undergraduate and postgraduate education.

Research on faculty perspectives of laboratory education should inform studies on students’ perspectives, and vice versa. For example, conceptual development is argued to be one of the key cognitive learning goals that students may wish to pursue. However, in a previous study, a comprehensive list of learning goals was not always available for the students\textsuperscript{57}. Thus, they did not have an overview of their conceptual learning trajectories. The notion of coherence between the intended, the implemented, and the attained levels of curricular representations\textsuperscript{2}, as well as congruence with other parts of higher education\textsuperscript{58}, require shared understanding of curricular goals. Some insights from faculty perspectives in this study may indicate such correspondence\textsuperscript{58}, with a scope for better alignment.

Competence development in the laboratory from students’ perspectives can also be viewed through skill development, as substantiated by Burrows, Nowak, and Mooring\textsuperscript{59}. Their findings indicate that the highest level of such development goes beyond acquisition of laboratory skills, but also entails problem-solving and making connections between theory and practice. Students who do lab work in a problem-based curriculum tend to see the laboratory as a place to make mistakes, whereas those who do traditional curriculum tend to avoid making mistakes\textsuperscript{59}. Likewise, in our results, faculty mentioned ‘making mistakes in the lab’ as a part of learning process, which is also identified in deKorver & Towns’s study mentioned above\textsuperscript{57}. This underlines the importance of looking at competence development from both faculty and students’ perspectives.
LIMITATIONS
While conversations among the faculty provide a rich and reasonably thick description, their perspectives may not be based on formal observation studies. Triangulation with other types of data, such as field observations and discourse analysis in the laboratory may strengthen the findings.

We used focus groups to elicit faculty perspectives on student learning. Although we argue that a list of learning outcomes provided a contextual information for their collective reflection, it may also limit the scope of their discussions. The tension between deductive and inductive approach to this form of data collection is presumably a trade-off we have to manage, but since this study is essentially a contextualization of the review, we had to start with a deductive approach.

CONCLUSION AND IMPLICATIONS
Qualitative data analysis of focus groups in this study sheds light on laboratory instructors’ perspective on student learning in the laboratory of pharmaceutical sciences. The faculty in the present study recognize, can relate to, and observe the many dimensions of learning in the laboratory, to various degrees. Discourse among the faculty focused primarily on the development of experimental competences, unless they were encouraged to discuss about other categories of learning outcomes. This shows the importance of encouraging practitioners to verbalize their tacit knowledge about relevant but less familiar pedagogical constructs.

Our study reaffirms the often-debated notion of inquiry approach to laboratory instruction and curriculum design\textsuperscript{3,60-62}, as instructors highlight its value in terms of higher-order thinking skills, affective outcomes, and epistemic learning. However, there is still a place for more prescribed protocols in introductory courses, in which students learn the basics of techniques, safety procedures, and data-related skills. We have situated our study in a broader literature of chemical sciences and we could identify similarities between pharmaceutical sciences, including pharmaceutical chemistry, with more traditional chemistry subjects.

Laboratory instructors play a crucial role in establishing dialogues with students to help them connect theory to practice, foster critical thinking, as well as reflect on data quality and the limitations of scientific knowledge that underpins experimental results. To assume such role, they should be competent beyond demonstrating or assisting in performing experiments, which begs a question whether laboratory instruction should be given by faculty or graduate teaching assistants; or whether
the latter should be trained more adequately to be able to assume the abovementioned pedagogical role\textsuperscript{63-65}. In this study, all laboratory instructors are faculty members.

Collaboration between educational researchers and practitioners is strongly encouraged to develop faculty’s pedagogical content knowledge. The present study shows that laboratory instructors should deliberate how students actually learn through experimental work, by focusing on evidence of learning outcomes (the attained level of curriculum representation)\textsuperscript{7,20} in lieu of solely the intended and implemented levels. Research can inform how and which of these outcomes can be enhanced.

This study could inform curriculum design and faculty professional development, through a dialogic approach that relies on evidence from research. This study is a first step to such realization in our setting. Moving forward, we are deploying insights from this study to raise awareness of research-based teaching in the laboratory of pharmaceutical sciences.

ASSOCIATED CONTENT
Supporting Information
The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX.
Contains excerpt of generated codes, examples of quotes, and emerging themes

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REFERENCES
1. Seery MK. Establishing the laboratory as the place to learn how to do chemistry. Journal of Chemical Education. 2020;97(6):1508-1511.
2. Agustian HY. Considering the hexad of learning domains in the laboratory to address the overlooked aspects of chemistry education and fragmentary approach to assessment of student learning. Chemistry Education Research and Practice. 2022;23(3):518-530.


8. Gammelgaard B, Christiansen FV, Nielsen JA. Improving Quality of Laboratory Learning at University Level (IQ-Lab): Project Description.; 2018.


52. Osborne J. The role of argument in science education. Research and the Quality of Science Education. Published online 2005:367-380.