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RESEARCH ARTICLE

What denotes progression in laboratory learning? Analysing a pharmaceutical bachelor programme

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Abstract

Background: This article explores learning progression within laboratory education. It aims to delineate the characteristics of learning progression across cognitive, social, and affective learning domains and on a structural programme level. **Methods:** The study employs a longitudinal approach involving interviews conducted over one academic year to assess progression. It also analyses programme and course descriptions for the third year in the pharmaceutical bachelor's programme. The empirical material underwent further analysis, focusing on perceptions of learning and utilising the Structure of the Observed Learning Outcome (SOLO) taxonomy. **Results:** The study shows that both instructors and students perceive learning progression as evolving from structured coursework to more autonomous thesis projects. The synthesis of the analysis indicates that intended learning outcomes represent a progression in five distinct clusters of learning outcomes. The study thereby contributes to understanding the connection between course activities, the intention of a bachelor's project, and learning progression and prompts questions on how to design for progression in higher education. **Conclusion:** This study presents empirically derived learning outcomes that demonstrate the progression of laboratory-based learning outcomes, highlighting independence as a crucial element.

Introduction

Pharmacy education aims to train students to become independent learners and prepare students for a future career in healthcare or industry. Learning in the laboratory is an integral part of pharmacy education and provides students with an understanding of specific laboratory procedures, quality control, and drug development (Bretz, 2019; Anakin & McDowell, 2021; Seery *et al.,* 2023). Laboratory work affords unique learning outcomes in chemical sciences (Reid & Shah, 2007). A recent review argued that research into laboratory learning should consider the complexity of learning outcomes and take steps to investigate the processes that influence their development (Agustian *et al.,* 2022). It also showed that higher education laboratory learning outcomes can be grouped into five clusters, i.e., experimental competencies, disciplinary learning, higher-order thinking skills and epistemic learning, transversal competencies, and the affective domain (Agustian *et al.,* 2022). Thus, this review mapped the types of outcomes resulting from laboratory learning but did not describe how progression can be achieved within each of the learning domains. A recent review of the literature on learning progression concluded that research would benefit from acknowledging the complexity of learning and employing a longitudinal view of learning (Jin *et al.,* 2019). The present work is a longitudinal study of learning progression within the five clusters of laboratory learning outcomes during coursework and the ensuing bachelor's projects in the third year of the pharmacy programme at the University of Copenhagen.

In the progression of the laboratory curriculum, first-year courses are traditionally highly structured and progressively organised towards final-year courses that are more focused on the student's independent critical reflection on practice (Prades & Espinar, 2010; Seery *et al.,* 2019). Although some elite pharmaceutical programmes are founded on the idea of inquiry-based teaching, with an emphasis on student autonomy from the first year (Meijerman *et al.,* 2016), they still focus on increasing student autonomy throughout the programme. In all programmes, instructors and course planners must settle on a few intended learning outcomes and communicate their integration with teaching and learning activities and assessment tasks to ensure constructive alignment (Biggs & Tang, 2011). This study applies the established framework Structure of the Observed Learning Outcome (SOLO) to sharpen the focus on learning outcomes.

The SOLO taxonomy is empirically developed and describes a specific performance at a particular time. It is arranged in five steps, i.e., prestructural, unistructural, multistructural, relational, and extended abstract (Biggs & Collis, 1982). The SOLO taxonomy has previously proven useful in research on pharmaceutical and laboratory education, e.g., in evaluating learning outcomes of e-learning tools (Karaksha *et al.,* 2014; Baumann-Birkbeck *et al.,* 2015) and within higher education to develop a rubric for capturing students' knowledge progression (Ramberg *et al.,* 2021). The SOLO taxonomy was also chosen as the framework in the context of broader development for laboratory experts in the global health sector (Albetkova *et al.,* 2019). With a specific focus on learning in the laboratory, this study takes its departure from the empirically based learning outcomes (Agustian *et al.,* 2022) and suggests a way of progression in learning within each of the five clusters, which are described as potential outcomes of laboratory learning. This study aims to investigate the learning outcome as explained, seen, and perceived by instructors and students, thereby contributing to new insights into how learning progression can be achieved within the different domains of laboratory sciences.

Research question

This study explores the perception of progression in the third year of pharmaceutical education through the analysis of official university documents, i.e., programme and course descriptions and interviews with students and instructors, guided by the research question:

How do instructors and students express the progression in learning outcomes from the context of two laboratory courses to the context of a bachelor's project?

The study contextualises the perception of learning progression in a pharmaceutical programme within the five laboratory learning clusters. In this context, the study aims to provide new insights into how laboratory learning outcomes evolve and are perceived differently during the transition between laboratory courses and bachelor's projects.

Methods

Educational context

This research was conducted in the third and final year of the Bachelor of Science (BSc) in Pharmacy at the University of Copenhagen (UCPH). This programme follows the 3+2 Bologna structure, with three years for the Bachelor of Pharmacy degree and two years for the Master of Pharmacy. Most students continue into a two-year master's education, as is common practice in Danish higher education (Danmarks Statistik, 2017; Hovdhaugen & Ulriksen, 2023).

Only about 15% of the graduates from UCPH work as pharmacists in community and hospital pharmacies. With most candidates pursuing careers in the sizeable Danish pharma and life science industry, the bachelor programme is structured with a heavy focus on natural sciences such as organic, physical, and analytical chemistry and biochemistry, but with a strong focus on drugs in all courses. Thus, the pharmacy programme at UCPH has a strong physical-chemical focus compared to many other pharmacy programmes in Europe.

Approximately 200 students distributed in seven classes are enrolled every year. The empirical material was collected in two courses that have a substantial amount of laboratory work and during the conduction of their bachelor's projects (Table I).

Table I: Context information

Course	Drugs from nature	Pharmaceutics 2	Bachelor's project
ECTS	7,5	7,5	15
Time period	Aug-Nov 2020	Aug 2020 - Jan 2021	Feb-Jun 2021
Lecture hours	25	40	4
Classwork hours	25	8	40
Laboratory hours	24	21	96
Estimated preparation	130	134	180*
Exam	2 hours written. Participation in laboratory exercises and report submission.	3 hours written. Participation in laboratory exercises and report submission.	Written project report. Oral examination

Data collection was conducted during three courses at the pharmaceutical bachelor's degree programme at UCPH. The third year also includes the courses Systems Pharmacology, Pharmacotherapy and two electives in which no data was collected.
*In addition, 82 hours of project work and 10 hours of supervision is estimated

Official documents

In coherence with the Bologna process and the European qualifications framework (European Commission, n.d.) Denmark and UCPH have implemented the Danish qualifications framework (Ministry of Higher Education and Science, 2021). Descriptions of the study programme (Faculty of Health and Medical Sciences, 2018) and the specific course descriptions (University of Copenhagen; 2020b, University of Copenhagen, 2020a) officially regulate the content of education and contain intended learning outcomes presented as objectives within competencies, skills, and knowledge (Christiansen *et al.,* 2015). The documents describe the intentions in the form of structure and curriculum requirements and provide detailed information on (intended) learning outcomes.

Interviews

One-hour semi-structured interviews were conducted with instructors and students during two third-year courses and bachelor's projects (Kvale & Brinkmann, 2015). Ten instructors and five students were interviewed, some multiple times, resulting in 23 interviews (Table II). Student participants were recruited through their learning management system while enrolled in the courses. Instructors were recruited by snowball sampling (Rosenthal, 2016), where the course-responsible teacher was interviewed and then suggested additional interviewees. All interviewees signed a declaration of consent per current data protection legislation. The study attempts to operationalise progression as a concept visible in official documents that instructors can explain and students experience. The nature of this concept is inherently complex to capture; as Ramberg and colleagues (2021) stated, "*there is no obvious way to describe students' overall progression in formal knowledge and skills from the first to the last year of higher education*." The approach here is grounded in a methodological argument aiming to capture developments over time, and the rigidity lies in multiple interviews with fewer people to capture the nature of progression. Questions from the interview guide are available in Appendix A. The interviews included open questions about the programme, the course, the exercises, and the five clusters of laboratory learning outcomes (Appendix B). Participants were asked to elaborate and discuss the five clusters of laboratory learning in their course (instructors) or for themselves (students). Thus, the interviewees were introduced to the clusters and used some words from the cluster descriptions in their continued reflections and explanations. An uninvolved outsider transcribed the interviews. Interviews, transcription, and analysis were conducted in Danish, and the final quotes for publication were translated into English.

Table II: Interviewed instructors and students and the context of the interview (23 interviews in total)

Interviewees	DfN	P2	B
T1	X		X
T2	X		
T3	X		
T4	X		
T5		X	
T6		X	
T7		X	
T8		X	
T9			X
T10			X
S1	X	X	X
S2	X	X	X
S3	X	X	X
S4	X	X	
S5		X	

T=Teacher, S=Student, DfN=Drugs from Nature, P2=Pharmaceutics 2, B=Bachelor's project

Analysis

The analysis of the empirical material was conducted in several steps, using the five clusters of laboratory learning (Agustian *et al.,* 2022) in both the research design and the analysis. First, the transcribed interviews were coded according to the five clusters of laboratory learning outcomes using NVivo (QSR International Pty Ltd., 2018). The analysis was conducted with a semantic and theoretical approach (Braun & Clarke, 2006), with the five clusters of laboratory learning outcomes used as the applied second step as a coding scheme. For instance, "*disciplinary learning*" included data coded as conceptual understanding, theory-practice connection, academic achievement, mastery, and disciplinary learning. Then, the results were compiled and sorted within each course and according to instructors and students, enabling analysis across each of the five clusters. As a third step, the sorted material was analysed concerning objectives, aims, goals, and outcomes. Then, the levels and verbs related to the SOLO taxonomy (Biggs & Collis, 1982; Biggs & Tang, 2011) were applied to synthesise a set of learning outcomes for each of the five clusters. In a fourth step, progression within each cluster was analysed with respect to experiences when students moved from laboratory courses to the bachelor's project. The synthesised objectives were then compared to the official documents. The analysis, discussion, and conclusions pertaining to the progression of learning outcomes were substantiated in all three sources of data, with teacher interviews, student interviews, and official documents serving as background for the educational context.

Results

The findings are presented in three themes as follows:
1) Progression of laboratory learning outcomes;
2) Progression as increased independence;
3) Consideration of the coherence of the three data sources: student interviews, instructor interviews, and official documents.

Progression of laboratory learning outcomes

Learning outcomes and progression related to pharmaceutical laboratory work were analysed using the five clusters of learning outcomes in laboratory work (Agustian *et al.,* 2022). The five clusters of potential learning outcomes of laboratory work are shown below with illustrative examples of relevant interview data.

Further, the SOLO taxonomy was employed to create a set of statements at different taxonomical levels from the empirical material. These statements are empirically backed by intended learning outcomes, showing progression within the five clusters. The analysis shows that the learning outcomes synthesised were generally lower for the laboratory courses and higher for the bachelor's project, indicating that the SOLO taxonomy can show a progression in this programme. Table III presents the synthesised aggregated learning outcomes from the interviews.

Table III: List of learning outcomes aggregated from interview data

Learning outcome	Laboratory courses	Bachelor's project
Experimental competences	**Unistructural:** *Identify* and correctly apply practical conditions of the laboratory, such as clothing, glasses, and cleaning. *Imitate* practical skills and practice and apply them in a professional and appropriate manner, such as weighing and changing apparatus settings. **Relational** *Apply* experimental protocols, e.g., Ph. Eur., and SOP, to conduct experiments and analyze data in specific situations.	**Relational:** *Construct* an original project by relying on earlier laboratory skills and then independently design, plan, and conduct experiments.
Disciplinary learning	**Unistructural:** *Recognize* concepts and theoretical ideas in the laboratory. **Relational:** *Integrate* content from laboratory exercises with content from other course activities.	**Extended abstract:** *Create* own experiments by understanding and using relevant connections between theory and practice.
Higher order thinking skills and epistemic learning	**Multistructural:** *Describe* why the analysis conducted in a particular exercise is as it is e.g. when it is based on the Ph. Eur. **Relational:** *Argue* if results are plausible by critically discussing procedures and identifying problems of methodological and practical character.	**Relational:** *Review* and *explain* sources of error. **Extended abstract:** *Create* procedures and critically evaluate them.

Learning outcome	Laboratory courses	Bachelor's project
	Extended abstract: *Reflect* about the purpose of laboratory work, herein recognizing elements that would be part of a future career in pharmaceutical academia.	*Hypothesize* why things turned out differently from expected.
Transversal competences	**Unistructural:** *Order* an efficient workflow and follow GMP. **Relational:** *Organize* collaboration. *Construct* and present written and oral data driven arguments in a clear manner.	**Relational:** *Plan* a substantial project report in collaboration. **Extended abstract:** *Reflect* on your own learning while monitoring own project. *Create* a substantial project report in collaboration.
Affective domain	**Unistructural:** *Illustrate* self-efficacy and confidence by adequate preparation and through opportunities to work independently. **Multistructural:** *Outline* own development of identity in relation to laboratory work. **Relational:** *Examine* and acknowledge contributions from surrounding conditions and other actors. *Solve problems* like demotivation by demonstrating professionalism and actively engaging.	**Relational:** *Explain* and *predict* your own affective reactions. *Make a plan* and iterate on it with independence, pride and meaning.

Learning outcomes are sorted in the five clusters with the corresponding action verbs relating to specific taxonomical levels in SOLO: Unistructural, Multistructural, Relational, and Extended abstract.

In Table III, the intended learning outcomes are sorted in the corresponding level of the SOLO taxonomy, indicated as U = unistructural, M = multistructural, R = relational, and E = extended abstract. Jørgensen (2023) provides a detailed outline of the SOLO taxonomy related to laboratory work. Furthermore, the intended learning outcomes were distributed across courses and the bachelor's project, providing another view of the contextual differences. The analytical argumentation is presented below for each cluster of learning outcomes.

Experimental competences

In this cluster, learning outcomes are related to the practical parts of the laboratory itself, such as familiarity with safety equipment and procedures, the use of glassware, and the handling of equipment akin to learning a craft. Emphasis is on following experimental and standard operating procedures of apparatus. As one student puts it:

> *"[we must] [F]ollow our protocol in every exact way" (S2 DfN).*

As a sign of progression, the analysis points towards decision-making and designing experiments as crucial features of the bachelor's project.

Disciplinary learning

Understanding theoretical concepts is an important learning outcome of laboratory activities. Either as a simple recognition of the relation between course elements or as a complex understanding of theory-practice connections. Instructors perceive the theory-practice connections to be established late in the students' learning process during the interpretation of the data, while students explain it the other way, indicating that they conduct the laboratory activities based on conceptions from theory and that the laboratory activities require theoretical insight:

> *"You have it in your hands and are allowed to actually see a finished product that I have… Something I have read in a book, now I have it in my hands. Now I have something we give to a patient. So that's like then you can finally fuse things together. It's not that separate anymore" (S5 P2).*

Further, students mention that they write theoretical sections of assignments independently of laboratory activities but that meaningful participation and understanding of laboratory activities require conceptual knowledge. Taking this complexity into account, the progression within this domain is expressed as the increased ability to relate relevant theory to the activities in the laboratory, as one teacher says when talking about the bachelor's project:

> *"[T]o define the project, to design the experiments, they [the students] must have adequate theoretical learning. If they do not understand the connection between theory and practice, well then it becomes a mess, then they don't get very far" (T9 B).*

Higher-order thinking skills and epistemic learning

Students are expected to participate in practical problem-solving and are asked to discuss methods and procedures. However, instructors are clear that the laboratory exercises are very tightly constructed with less focus on problem-solving as a higher-order thinking skill, e.g. when exercises are based on the European Pharmacopoeia:

> *"[T]he pharmacopoeia monograph is not necessarily the best method . . . you are actually working on a method that is not necessarily state of the art, but which is something that as many people as possible should be able to do" (T1 DfN).*

Instructors and students in both courses can envision the progression in the programme, saying that there are not many higher-order outcomes in the courses, but it will be a focus in the bachelor's project:

> *"I think it might be more if you are [in] bachelor's lab or something where you are a little more independent" (S2 DfN).*

However, some higher-order outcomes are also aimed at in the courses, and instructors are clear that students must apply critical thinking to evaluate their results to produce an appropriate laboratory report. Instructors interviewed about the bachelor's projects believed that students can learn higher-order outcomes such as thinking critically about their project, the results, sources of error, and developing and testing ideas. Similarly, students reported that bachelor's projects result in critical reflections about their own choices regarding experiments.

Transversal competencies

Interviewees described transversal competencies as basic skills like preparing, maintaining workstations, and following GMP. Collaboration is an essential transversal skill, where groups of students must work reasonably and efficiently within a given timeframe for an assignment, which entails distributing work within a group and then collaborating on a joint report afterwards:

> *"They do group work all the time. So they have to split up. . . . But still work together, help each other, and exchange [work] around in their group" (T8 P2).*

In addition, communication tasks related to oral discussion and producing a written report require students to develop argumentation.

Affective domain

One teacher mentioned that pre-lab activities force preparation, resulting in calmer students and better outcomes, where students emphasise how laboratory work adds to their motivation and enjoyment when it is not repetitive. In the Pharmaceutics 2 course, the concrete production of pharmaceutical products was motivating because of the clear contextualisation, which provides success for the students and contributes to their identity as pharmacists. When writing a bachelor's thesis, students are expected to take ownership and engage in activities that strengthen their meaning-making. As one student summarised, the affective outcomes for students are influenced by the situation, including instructors, technicians, classmates, and established safety measures; it becomes engaging when instructors themselves are engaged.

While the analysis is not exhaustive, the empirical material does indicate a progression within each of the five clusters of outcomes described by Agustian and colleagues (2022). The analysis of interviews with instructors and students from three courses over a year using the SOLO taxonomy shows an empirically supported progression within each of the five clusters. Signs of progression in experimental competencies were decision-making and designing experiments in the bachelor's project in contrast to courses. Progression within the disciplinary learning cluster was expressed differently by instructors and students but was, in general terms, characterised by the increased ability to relate relevant theory to laboratory activities. The clusters of higher-order thinking skills and epistemic learning were less represented in the laboratory courses but came into focus when students worked on their bachelor's thesis, supporting the findings indicating a progression between courses and the project. Progression within the transversal competencies and affective domains was less visible but referred to students being able to work and communicate in the laboratory, thereby taking more ownership and feeling motivated. Progression in the affective domain was also linked to gaining more independence, as the next part of the analysis explores further.

Progression as independence

Analysis of the empirical material with a progression lens showed that both instructors and students identified a clear connection between progression and independence. Independence, expressed as the "lack of it" in courses, contrasts with the explicit expectation of student independence in the bachelor's project (where students plan and conduct an autonomous laboratory-based project). The term independence has previously been associated with self-efficacy and deep learning; Micari and Light (2009) used the framework of self-efficacy (Bandura, 1997) to analyse how chemistry students develop independence in managing their learning through a peer-feedback system. They showed how independence is related to "the sense that students rely on themselves as much as, or more than, external supports to enhance their learning", helping students gain a deeper understanding of the course content as they take responsibility for their motivation and create meaningful learning (Micari & Light, 2009). A review of biology education highlighted how creating structures that foster deep learning is desirable and advocated for "adjusting course norms and practices to promote deep approaches to learning" (Google *et al.,* 2023 p. 47). Analysis of the empirical material revealed that independence was linked to the structure of the courses (course norms) and individual student learning, which, in turn, was associated with enhanced problem-solving skills, considered here as a proxy for deep learning.

The main difference between the courses and the bachelor's project lay in the design of the laboratory work and the expectations regarding how students work. Instructors described how they design laboratory work as assignments with a clear workflow and instructions in courses. The laboratory work was constrained to the purpose of teaching students to follow a protocol or be able to repeat experiments.

> *"They do not learn that so much here [in this course]… We're still in some cookbook… Or it's a description of exactly what they're doing. Take this, mix it up. There is a SOP by the apparatus… It's more in the bachelor's part that they learn to design experiments" (T6 P2).*

> *"[T]hey simply become better at being in the laboratory, and they become better at handling, doing experiments. . . I allow myself to call it a craft. Sometimes chemistry and analytical chemistry are crafts" (T1 DfN).*

The contrast became apparent with the description of the bachelor's project as an open exploration: students are expected to apply their knowledge, practical skills, and experimental competencies developed from previous courses and work independently from idea to design and data analysis.

> *"[T]hey [the students] must constantly design and plan experiments, they must perform them themselves, they must analyse data themselves. They really use some of what they have learned in the laboratory and must work independently and apply these practical skills" (T9 B).*

Students experienced this additional expectation of independence in the bachelor's project as an increased responsibility for making decisions and managing the research process, which was both challenging and empowering:

> *"[I]n the bachelor's lab... we have had to be much more independent. At the same time, it has also been a lot of fun, because we had to go and do what we have planned… [it is] more fun to do the work because you can see the point of it" (S2 B).*

This student further reported enhanced independence in the explicit expectations of the written assignment:

> *"We prepare a longer written assignment about the laboratory, where we have both theory and method" (S2 B).*

The more open-ended process of the project underlines the progression from the more tightly structured laboratory activities in the courses to the independent learning process in the bachelor's project.

The progression between the courses and the bachelor's project is further evident in instructors' expectations of problem-solving. In the courses, students critically analyse data and solve specific problems when they get unexpected results from following protocols. However, advanced problem-solving is postponed until the bachelor's project:

> *"[W]here they must really get started with problem-solving" (T8 P2).*

The students experienced the transition as new types of expectations, i.e., being critical and making choices in their independent project. The progression from coursework to working on the bachelor's project was understood by both instructors and students as increased responsibility in decision-making, managing, and carrying out the project.

The above analysis of learning outcomes linked to the affective domain shows that students were more 'motivated' and 'took charge' of their learning when they had the opportunity to work independently on their bachelor's project. Therefore, independence is also linked to the affective domain, and feeling more secure or being able to solve problems in the laboratory is a way of supporting students' self-efficacy, which, in turn, is linked to increased independence. In summary, the analysis reveals signs of progression in students, with enhanced independence illustrated by advanced problem-solving skills and increased responsibility for taking charge of processes and work in the laboratory.

Coherence of data

The analysis above shows a shared perception among instructors and students about the courses as meant to scaffold student competencies towards later independence. That transition is also evident from the analysis of the programme and course descriptions.

The programme description highlights how graduates can independently analyse, evaluate, and solve pharmaceutical scientific problems and how students must learn to work according to GLP and GMP (Faculty of Health and Medical Sciences, 2018). The Pharmaceutics 2 course description focuses on learning to use apparatus and produce drugs by following standard operating procedures (SOP) of equipment while following and documenting GMP. Hence, the goals section states: "*The objective of the teaching is to provide students with knowledge about formulation and production of solid dosage forms, including the most important pharmaceutical unit operations, and the corresponding principles and apparatus*." (University of Copenhagen, 2020b).

The course Drugs from Nature focuses on procedures and the corresponding apparatus that students learn to use in concordance with the European Pharmacopoeia. However, the course description states that "(*Students learn to*) *act independently as central figures in cross-disciplinary research projects*" and that they should take responsibility for planning experiments (University of Copenhagen, 2020a). Some level of independence is expected here, but not to the same extent as in the bachelor's project, where students should take responsibility and independently plan, design, formulate, produce, and evaluate a drug (University of Copenhagen, 2020c).

The official intended learning outcomes, the expectations from instructors, and students' experiences are coherent in that progression is expressed as increased independence. Thus, independence is mentioned by instructors, students, and official documents and is a substantial part of how progression is viewed in this particular programme.

Discussion

The analysis shows a progression of learning in the transition from the context of laboratory courses to the context of the bachelor's project. The bachelor's project was experienced by instructors and students as more open-ended and with opportunities to obtain relational and extended abstract types of learning outcomes (e.g. problem-solving) to a much higher degree than the laboratory work of the previous courses.

Current literature on problem-solving indicated that introducing teaching that develops pharmaceutical students' problem-solving skills can expose students to a steep learning curve (Lipari *et al.,* 2022), while research in a chemistry context showed that explicitly focusing on problem-solving can be used effectively by teaching assistants as a scaffolding teaching tool (Vo *et al.,* 2022). In relation to this, the SOLO framework emphasises that the learners are active in their development (Biggs & Collis, 1982), which shows the importance of independence in learning. Synthesising learning outcomes in the SOLO framework provides a theoretically strong view of progression, which can be helpful in scaffolding. Therefore, the recommendation for future research is to consider investigating how problem-solving activities can be scaffolded and coordinated at the programme level.

The learning outcomes described here link the SOLO taxonomy with the five clusters of laboratory learning outcomes (Agustian *et al.,* 2022) and add to the understanding of both frameworks, as multiple taxonomical steps are at play in all five clusters. Thereby, student learning can occur at numerous taxonomical levels in various clusters. The implication for practice is that instructors and students could benefit from being aware of the complexity of learning outcomes in the laboratory to become more reflexive instructors and learners.

Concerning constructive alignment and transitions between courses, findings within health education have recently shown issues with the transition experience in all years of study, concluding that instructors should understand their teaching in the context of the whole programme (Birbeck *et al.,* 2021). In addition, university courses have often been criticised for being planned in isolation (Biggs & Tang, 2011; Jessop & Tomas, 2017). Contrary to this, the courses in the third year of the pharmaceutical programme at UCPH appear to be reasonably coherent, as third-year instructors are aware of other course activities, content, and aims, and there is general agreement on how progression should be implemented. This awareness could be an opportunity to discuss activities with more independent student laboratory work throughout the third year and thus avoid the bachelor's project as the primary carrier of the learning outcomes that this affords. These discussions should touch upon the overarching aims of the programme, what kind of pharmaceutical scientists the programme aims to educate, and what the programme might look like in the future. An example is the differently constructed pharmaceutical programme at Utrecht University that focuses on more independent and inquiry-based learning for excellent students (Meijerman *et al.,* 2016). The argument is that independent, more open-ended, and inquiry types of laboratories are preferable from a learning perspective (Bybee, 2006; Reid & Shah, 2007). However, there is some evidence for the importance of closed and tightly structured settings in pharmaceutical laboratory education. A plethora of intended learning outcomes are related to specific handling of apparatus, good manufacturing practices, standard operating procedures, quality assurance and batch documentation. An argument is that these features are at the core of pharmaceutical science to a degree that distinguishes it from related fields. As central practices in the pharmaceutical landscape, it is highly relevant to educate future pharmaceutical experts in these concepts and understand why some interviewees emphasised this feature of the programme. However, this point appears to be somewhat absent from the literature on pharmaceutical education, with one exception having it as a competency for experts in general health systems laboratories (Albetkova *et al.,* 2019).

Meijerman and colleagues (2016) discussed how the programme succeeded, with instructors approving laboratory protocols early and in closed laboratory settings and then moving into a more consultancy role of continued discussions throughout a project in later and more open laboratory activities. This different expression of progression is linked to gradually creating more open activities with increased student autonomy. Another framing of programme-level progression is to move from well-defined protocol experiments to unfamiliar, open-ended, and ill-defined experiments throughout the programme (Seery *et al.,* 2019). From a teaching perspective, this is not a simple task. The present research adds to the ongoing debate on expository versus open-ended explorations, which is relevant for all higher education programmes that include laboratory work.

Limitations

Limitations of this work include that only a single pharmaceutical programme was studied. It could be relevant to conduct a similar investigation elsewhere, as perspectives on progression and learning outcomes might differ significantly between contexts. Another limitation is the unknown influence of COVID-19 restrictions that change during the study.

Conclusion

This study explored instructors' and students' views on laboratory learning outcomes and how progression is expressed in the third year of a higher education pharmaceutical programme. With a longitudinal research design across two courses and a bachelor's project, the study found that instructors and students could recognise signs of progression within all five clusters of laboratory learning. Through analysis of interviews with instructors and students, the study found an empirically supported progression linked to experimental competencies, such as decision-making and designing of experiments in the bachelor's project. Further, progression within the disciplinary learning cluster was characterised by students' increased ability to relate relevant theory, where higher-order thinking skills and epistemic learning were most pronounced in students' work with their bachelor thesis. Signs of progression within the transversal competency cluster and the affective domain were linked to students taking ownership and feeling motivated as they worked more independently in the laboratory. Using the SOLO taxonomy's theoretical framework, the results nuanced the five clusters by showing how learning outcomes from interviews with participants in a specific educational context could lead to an overarching discussion of a programme's intentions and aims.

The implications for practice include awareness of the different learning outcomes in specific courses and how the progression of laboratory learning within the five clusters may be described, a central question in curriculum and course planning. The detailed analysis contributes to understanding the connection between course activities, the intention of a bachelor's project, and learning progression as described by students and instructors. These insights lead to reflections on the programme intentions and the conceptions held by instructors and students and prompt questions on how to design for progression in higher education. In addition, the implications of choosing open or closed laboratory teaching activities warrant further discussion and research into the nature of pharmaceutical sciences concerning teaching development. In describing pharmaceutical education, there is reason to consider how progression within learning domains aims to foster broader concepts such as independence. How does 'progression for increased independence' relate to the development of students' self-efficacy and discipline-specific types of competencies and professional judgments in pharmaceutical practice? For instructors, the question is how these goals can be pursued in relevant types of learning activities. This question also involves consideration of disciplinary diversity, i.e., how pharmaceutical laboratory education differs from laboratory education in related scientific fields.

Ethics approval and informed consent

The research project follows the Danish Research Ethical Guidelines, and all participants have signed informed consent forms.

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Appendix A: Questions for teachers and students

A.1 Questions for teacher interviews

Subject	Question	Materials
Course aims	What is the aim of this course?	Course description
This course in the program	Please describe the purpose of this course in the program Why is the course now?	Overview of program
Before and after this course	What do you expect the students can do prior to this course? What can the students take away from this course? For their bachelor's project For their master's education For their future career	Overview of program

Subject	Question	Materials
Exercises in the course	You have these exercises in the course. What is their role? What are the students' takeaways of these exercises? The literature points to these possible outcomes of laboratory learning. What is particularly relevant for your exercises?	Course overview with exercises Laboratory learning outcomes from Agustian et al. 2022
About one exercise	Which of these exercises especially contribute to developing the students' laboratory skills? What is the learning outcomes of this exercise? How do the students approach this exercise? What is easy/difficult for the students in this exercise?	Laboratory learning outcomes from Agustian et al. 2022
Feedback for exercise	How is feedback organized? How can the students use the feedback?	

A.2 Questions for student interviews

Subject	Question	Materials
Course aims	What is the aim of this course? What have you learnt at this course?	Course description
Before and after this course	What have you learnt earlier that you can apply at this course? Where did you learn it? What about lab work and report writing? What can you take away from this course? For your bachelor's project For your master education For your future career	Overview of program
Exercises in the course	You have these exercises in the course. What is their role? What are your takeaways of these exercises?	Course overview with exercises
About one of the students' reports and feedback	Here is one of your reports and the comments you received How did you approach this exercise? What was the takeaway of this exercise? What was easy/difficult for you in this exercise? Let us take a look at some of the comments you have received What do think of the comments? How did you use the comments? How could the comments be more useful? Literature points to these possible laboratory leaning outcomes. What is especially relevant your exercises and reports in [this course]?	Reports and comments Laboratory learning outcomes from Agustian et al. 2022

Appendix B: Table used in interviews to discuss laboratory learning outcomes.

Clusters of learning outcomes	Substantiated constructs
Experimental competences	Practical skills Conducting experiments Data analysis and interpretation Experiment design
Disciplinary learning	Conceptual understanding Theory-practice connection Academic achievement and mastery
Higher-order thinking skills and epistemic learning	Problem-solving Critical thinking Argumentation Metacognition Reasoning and reflection Epistemic learning

Clusters of learning outcomes	Substantiated constructs
Transversal competences	Collaboration Communication (oral and written)
Affective domain	Expectations Interest, enjoyment, and engagement Self-efficacy Laboratory anxiety Motivation Self-regulation Professional identity

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