DUT 37
Årgang 20, nr. 37, 2025

Videnskabelig artikel, fagfællebedømt

Being in the teaching laboratory: Explorations of instructors' discourses about learning progression

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Abstract

The laboratory has long been conceptualised as central for learning science in higher education. Students are provided with possibilities to learn content and develop skills, thereby gaining experience, practice, and confidence working in a laboratory. However, the affordances of the laboratory as a space where humans interact with each other as well as materials and technology are understudied from a learning perspective. By drawing on the post-phenomenological philosophy of technology, this study argues for including a sensitivity towards both the socio-cultural and socio-material in explorations of learning in the laboratory. To develop this argument, the article offers a qualitative study of instructors' discourses and observations of students' laboratory-based learning. Grounded in socio-cultural and socio-material analysis, I show how instructors conceptualise changes in student behaviour as a proxy for learning progression, as technologies become a part of their movement and of being in the laboratory.

Introduction

Higher science education research has a long history of pointing to laboratory work as a central practice for teaching and learning science (Bretz et al., 2013; Agustian et al., 2022a). The teaching laboratory is understood to provide students with the opportunity to learn through concrete engagements with instruments and materials, and serves as a space to teach a wide array of competencies, including scientific content knowledge, methods, procedures, and the production of scientific data (Bretz, 2019; Seery, 2020). Research points towards learning outcomes in, for example, chemical sciences to be supported by teaching in the laboratory (Reid and Shah, 2007; Agustian et al., 2022b), leading to higher education research often focusing on laboratory work and being concerned with improving teaching in the laboratory (e.g., Seery et al., 2024).

Research on learning progression and students' outcome of higher education (Duschl et al., 2011; Caspersen et al., 2014) takes many forms and uses various methods, from standardised progress tests (e.g., Freeman et al., 2010) to students' self-reported satisfaction or development (Humburg and van der Velden, 2015) or value-added approaches (Liu, 2011). Learning progression in relation to laboratory work is often assumed implicitly, as students seem to be 'active' and across time pick up the ways of working in the laboratory (Jørgensen et al., 2024). Generally, the notion is that 'there is no obvious way to describe students' overall progression in formal knowledge and skills' (Ramberg et al., 2021 p. 249) in higher education, which opens up for multiple ways to operationalise and research learning progression.

In this study, learning progression is explored in the context of teaching laboratories in higher education institutions, and these are seen as learning spaces embedded in disciplinary practices and influenced by cultural

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norms. Disciplinary practices include aspects such as becoming part of a learning community (Lave and Wenger, 1991), shared language including signs and codes (Hasse, 2002), as well as disciplinary identities (e.g., Günter et al., 2021; Madsen and Malm, 2023), disciplinary values (Neumann, 2001), and norms in science (Anderson et al., 2010). All of these elements point towards the same concept: that the practice of science is a social process (Lemke, 1990) and laboratories are spaces of the social practice, shaped by disciplinary norms. Consequently, learning in a laboratory provides an entry point into the cultural practices inherent in scientific disciplines, encompassing how scientific knowledge is generated, used, and valued. This socio-cultural stance widens the conceptualisation of what the laboratory is and points towards larger (societal and cultural) structures influencing the teaching and learning environment.

In science practices, we see that as soon as some practices become normalised, others are marginalised, thereby providing some scientific culture(s) with value while others are rendered unintelligible (e.g., Günter et al., 2023). This normalisation also influences and manifests in instructors' perceptions of what constitutes 'good' student participation and 'good students' (Brickhouse, 2001), leaving *some* students' performances celebrated and recognised within the practice (Barton and Yang, 2000). Instructors are important in both (re)producing the academic culture and constructing students' learning environments as 'key agents in the creation and maintenance of university discourse' (Wong and Chiu, 2020, p. 55). In Wong and Chiu's (2020) exploration of instructors' ideas about an 'ideal' student, they use the concept of 'imagined identity' (De Ruyter and Conroy, 2002) to illustrate how instructors also construct imagined identities of students. As such, they find that an ideal university student is imagined by lecturers and suggests that the expectations influence student learning outcomes (Wong and Chiu, 2020, p. 55). Work on 'ideal students' (e.g., Tange and Jensen, 2012; Wong and Chiu, 2021; Chiu et al., 2021; Gregersen and Holmegaard, 2022; and Wong et al., 2023) shows how implicit expectations within a specific context direct student engagement and ideas about who they should become. Instructors' discourses are in this sense powerful, as they both shape and direct the disciplinary culture, including the learning environment.

With the specific interest in learning progression in the teaching laboratory, discourses are one entry point to exploring socio-cultural processes in laboratory spaces. Moreover, adding a materiality perspective takes us even closer to the laboratory as an educational context, where both humans and technologies have agency and become contributors to, and co-creators of, knowledge (Barad, 2010). From a materiality standpoint, the laboratory environment, instruments, active bodies, and the object of research are all intertwined in the creation of meaning, knowledge, and discourse (Barad, 2007). When exploring learning in the laboratory, there is an argument for including materials and instruments, as well as socio-cultural discourses. The combination of socio-cultural and socio-material further provides an entry point to see how the 'correct' use of materials is another manifestation of (cultural) power in the laboratory setting, as it becomes more visible through physical engagements with materials. In other words, the tacit practice of laboratory work (Polanyi, 1966/2009) becomes a way to show competence in this practice, while being embedded in the disciplinary culture. By focusing on the tacit and embodied knowledge (Polanyi, 1966/2009), the materiality (Barad, 2007; 2010) as well as the technological mediations (Verbeek, 2005) in the laboratory, it is possible to show multiple axis of interactions within teaching laboratories. As Roehl (2012) points out, the post-phenomenological approaches create an analytical shift in educational research that 'make visible what usually resides in the background' (p. 119). With inspiration from these theoretical frameworks, this study offers an entangled analysis of the material and cultural practice of laboratory work in science, guided by the questions:

- How do instructors conceptualise 'learning in the laboratory'?
- What do they report to be signs of student 'learning progression' in teaching laboratory contexts?

In this study, I explicitly use the term *teaching laboratory* to distinguish teaching spaces that host laboratory work from research laboratories. In the following, I outline the study's socio-cultural perspective and characterise socio-material entanglements in the teaching laboratory. The analysis delineates the most prevalent discourses of learning progression and explores how these can be understood in the light of the affordances in the teaching laboratory.

Background

Powerful discourses

Discourses are shaped by language and gestures in a context where individuals establish, transform, or reinforce norms. Broadly, discourse as a term refers to 'a particular way of talking about and understanding the world (or an aspect of the world)' (Jørgensen and Phillips, 2002, p. 1). Actions and statements prevalent within a discourse can be viewed as narratives through which individuals negotiate their subject positions or roles. Michel Foucault (1975/2002) furthermore asserts that discourses influence not only human perception of the world and reality but also self-perception. Power becomes effective by rendering desirable behaviours visible, while undesirable behaviours are disregarded, rendered invisible, and possibly penalised (Foucault, 1975/2002). Individuals tend to align their actions with prevailing norms to evade being labelled as deviant, and therefore become a fundamental requirement for the functionality of normalising power by the presence of self-regulating subjects who adhere to and reproduce established norms (Foucault, 1993). The term 'culture of power' (Barton and Yang, 2000) refers to the same process where powerful practices are not challenged. Within powerful discursive practices, such as laboratory work, we shape discourses that shape culture, as much as culture shapes the discourses. Prospects for change therefore also exist within discourses; however, these processes of change are interwoven with structural changes, specific interests, and individual agency (Leipold and Winkel, 2017). Here, the notion of power is important as it resides in interpersonal relationships and is articulated through language and actions, delineating what is acceptable or unacceptable within the boundaries of the discourse 'normality' (Foucault, 1975/2002). Intimately intertwined with subjects, discourses shape actions.

Tacit knowing and knowledge production in the laboratory

As the practice of laboratory work includes the physical use of instruments, paying attention to tacit and embodied knowledge is central. Michael Polanyi's *The Tacit Dimension* (1966/2009) draws on two forms of knowing, the intellectual 'knowing what' and the practical 'knowing how', and he argues that they 'have a similar structure and neither is ever present without the other' (p. 7). He therefore terms this *knowing*, 'to cover both practical and theoretical knowledge' (Polanyi, 1966/2009, p. 7). The framework outlines the complex nature of knowledge, emphasising the interplay between explicit and tacit elements of knowledge, and states, 'we can know more than we can tell' (Polanyi, 1966/2009, p. 4). This refers to the knowledge that is integrated in our bodies, which makes it difficult to explain to others. The use of instruments becomes central, as Polanyi (1966/2009) understands the use of tools 'as further instances of the art of knowing' (p. 7). He argues, 'when we make a thing function as the proximal term of tacit knowing, we incorporate it in our body – or extend our body to include it' (p. 16). Through our use of an instrument, we gain a bodily knowledge that enables us to conduct the practice more precisely or correctly, but it makes it difficult to evaluate our knowledge as it becomes embodied.

Laboratory entanglement(s) and technological mediation

Polanyi (1966/2009) argues for knowledge as both practical and theoretical, and strongly linked to practices within a discipline. Karen Barad's concept of knowing-in-being (2007) helps us to see how instruments become material agents the students learn with and from in the disciplines. In their book *Material Practice and*

Materiality: Too Long Ignored in Science Education, Milne and Scantlebury (2019) refer to Karen Barad (2003) and argue for paying more attention to matter:

> *"Science education research has a tendency to ignore material culture focusing instead on social culture through constructivist lenses in which language is used as the arbiter of social practice" (Scantlebury and Milne, 2019, p. 1).*

Material practice is ignored when researchers solely base studies on a socio-cultural examination of language, as well as in the tendency to centre the human in research (Scantlebury and Milne, 2019). When Barad (2003) suggests that language has been assigned too much power in cultural production, she turns our attention to how both humans and non-humans (i.e., materials, places, and discourses) become co-creators in knowledge constructions (Barad, 2010). Applying a materiality lens is therefore useful when illuminating multiple axes of interactions and entanglements. It directs us to pay attention to the particular intersection between humans (their doings) and non-humans (the instruments) in a teaching laboratory setting. Rather than exploring *if* the materiality of instruments plays a role in student learning, we explore *how* students' bodies and movements interact with the materiality of the laboratory.

Peter-Paul Verbeek's (2005) framework of technological mediation also directs us to think of instruments or technologies as not only in the middle between humans but as involved in the shaping of who we are; they are considered to have agency. The core premise is that technologies actively contribute to shaping the interactions between people and the world around them (Verbeek, 2005, p. 108). Verbeek's mediation theory departs from the 'post-phenomenological' approach in the philosophy of technology founded by Don Ihde (2009) and has two dimensions of implication. On the one hand, technologies help shape how human beings are in their world and, on the other hand, how the world is there for them (Verbeek, 2005, p. 165-8). This means that our technologies are involved in any dimension of society and human existence, thus mediating our knowledge of the world and challenging the most basic categories and our thinking. Drawing on Verbeek's (2005) concept of technological mediation, Roehl (2012) poses the questions: 'Which actions are made possible by an object? Which ones are hindered? How do objects engage us via our sensory perception?' (p. 118). These questions point us to reflect on what agency objects have to change our experience and relation to the world, and Roehl (2012) argues that the post-phenomenological perspectives can support a new reflexivity in educational research that brings forth diverse viewpoints. Both focusing on the materiality in Barad's terms and the post-phenomenological philosophy point us to think more thoroughly and critically about how instruments influence knowledge production and our socio-material interactions between students, instructors, and materials in the teaching laboratory.

Method

The empirical material includes interviews with instructors that explore ideas of laboratory work, learning, and learning progression in the context of the higher education teaching laboratory. The interviewees provided their informed consent and agreed to participate, in alignment with current data protection legislation in Denmark. This study used individual qualitative interviews to elicit instructors' experiences of teaching in the laboratory in one study programme and were conducted on campus in the instructors' respective offices in January 2023. One interview included a walk through a teaching laboratory as the instructor explained how they used the instruments for teaching and illustrated where students were struggling to handle machines. The instructors were chosen through a purposeful sampling strategy (Creswell, 2009) with the criterion that they had significant experience with teaching bachelor-level courses with laboratory work in the study programme. Six instructors were invited to participate in the study, and four accepted the invitation.

The interviews were semi-structured, following an interview guide that allowed for exploring topics as they occurred (Brinkmann, 2018). The initial interview guide (see Table 1) was designed to gain insights into instructors' experiences with teaching in the laboratory; specifically, in relation to how instructors recognise learning (e.g., 'What signs of learning do you observe?'), learning with materials (e.g., 'Can you describe how students learn to use instruments in the laboratory?'), and instructors' ideas of learning progression (e.g., 'How do you understand the term progression?' and 'How can you assess what the students have learned?'). The interviews lasted about two hours each and were completed by the author. An uninvolved professional transcriber transcribed the interviews in Danish. Selected quotes were translated into English by the author. Commas mark short pauses in the discourse or repetition.

Theme	Questions
Learning	When (or in which situations) do you experience that students have learned something?
	What signs of learning do you observe?
	In which situations do you experience that students can demonstrate what they have learned?
The Laboratory	Specifically in the laboratory, how do you see learning there?
	Can you describe how students learn to use instruments in the laboratory?
	How do you see that the students can handle operations and make choices themselves?
Progression	How do you understand the term *progression*?
	How can you assess what the students have learned? Can you give examples from the course you teach?
	Are there, for example, things the students do differently in the third year compared to the first year?

Table 1. Interview guide presented with themes and questions

Analysis

First, the produced transcripts were analysed thematically (Braun and Clarke, 2006) to grasp the full material. In this first part of the analytical process, six themes were identified. Significant quotes were chosen and this material was sorted into the six themes: students' preparation; interactions with students and types of questions; written products and language use; developing 'a feeling for'; use of materials; and impressions of students. In a second step, a detailed discourse analysis (Jørgensen and Phillips, 2002) aimed to gain a deeper understanding of the established discourses of the selected material for the six themes. The instructors' statements about learning progression related to laboratory work were analysed through their use of language to describe different acts, either explicit or implicit in the laboratory. Based on this third step, five interrelated themes were established. This was done to preserve the complexity of instructors' statements and stay true to the inter-relatedness that occurred in the material. The analysis therefore needed to accommodate more overlapping themes, which offered a more realistic presentation of the entanglement of learning in the laboratory. The results presented below are therefore designed with a short introduction of the identified interrelated themes, and then an analysis divided into three sections. The following analysis does therefore not aim to provide extensive analysis of the empirical material, but to offer examples of how utterances made by instructors can be interpreted when considering the wider context of culture, materiality, and laboratory spaces in higher education. Thus, the quotes are chosen to best illustrate the analytical findings.

Results

When instructors were asked to describe how they identify students' learning and learning progression in the teaching laboratory, they replied with a series of observations often tied to an explanation of how difficult it is to measure progression. One instructor noted:

> *"There are some hidden skills, because it's not something we ... It's not something we quantify; it's extremely difficult to describe. But we can just see that when you see them in the* third *or* fourth *year, they acquire the things we want them to be able to do in a laboratory. (...) It's not something we test, as such, because it's extremely difficult to test, and it might not even be so important to test" (Instructor 4, 2023).*

In this exploration of learning in the laboratory, these statements are characteristic of how instructors searched for the words to describe what they observe. However, as instructors talked, they drew on their experience as instructors in the laboratory as a physical as well as a social space. Overall, what they search for is students' change in behaviour as a proxy for learning.

> *"(...) there is a progression, but it's not because we introduce something that's more difficult for them. That's actually there all the way, but it's their focus that changes" (Instructor 2, 2023).*

> *"Well, it is their... it is the way they approach the material. If they themselves grab the pen and try to work things out, if they try to process the data in Excel, or grab the teaching material to try to put the pieces together to solve the problem" (Instructor 3, 2023).*

When prompted to reflect on learning progression, instructors struggled to describe how students' learning becomes evident, and their narratives are entangled with ideas of assessment, conditions for teaching, teaching in other courses, and their own teaching philosophy. The results of the analytical process are therefore not comprised of clear-cut themes, but interrelated themes demonstrating how instructors observe signs of learning and learning progression in the teaching laboratory:

- Observations of students improving their laboratory skills, students handle materials and perform simple tasks with more confidence.

- In dialogue with students, as they learn more, students ask fewer questions about practical matters in the laboratory and ask questions that are more theoretical.

- Observed that students are able to explain mistakes and offer explanations for how to solve them.

- As instructors work with the students on a shared problem, they develop solutions together.

- Observations of how students move in the laboratory space, as they learn to be in the laboratory.

The analysis shows that instructors' observations of change in behaviour is central, and the following analysis explores how these behavioural changes can be linked to socio-material affordances in the laboratory. The analysis offers a detailed unpacking of what instructors observe and interpret as learning, divided into three sections. The section *Laboratory skills as central for learning science* explores how skills are connected to learning in the laboratory. The second section focuses specifically on *Material agents and technological mediations in the laboratory* and how we can understand instructors' observations of changes in student behaviour. The third section explores *Students' spatial moves in the disciplinary culture* and connects what instructors' observe in students' movements and behavioural change in a socio-cultural analysis.

Laboratory skills as central for learning science

Instructors observe students improve their laboratory skills and characterise this as the most obvious sign of learning progression in the teaching laboratory. An instructor described how some students show signs of nervousness (e.g., shaking hands), as they weigh dry products on a scale for the first time. The instructor observed them becoming more confident:

> *"They have definitely gained some laboratory expertise, skills which you would not be able to train in other [settings]... I mean, it sounds very practical when you say it, but how do I weigh 50 mg precisely? (...) That is something you need to have worked with, with your hands ... Well, you can read about it, but you would never understand it until you have tried it yourself" (Instructor 4, 2023).*

This instructor's recognition of learning as linked to handling materials points to the connection between learning practical skills and learning scientific knowledge. Polanyi's term *knowing* is useful here as it links practical and theoretical knowledge (Polanyi, 1966/2009, p. 7) and draw our attention to the type of knowledge that is tacit, embodied, and therefore difficult to explain. The instructors observe students become better at performing practical skills with the instruments, and acknowledge that handling the instruments is important, as you will 'never understand it until you have tried it yourself' (Instructor 4, 2023), but in order to evaluate learning progression, instructors need more information. Instructors gain this through interactions with the students both during the time in a shared laboratory space and in dialogue with the students. In particular, instructors use the students' questions to evaluate learning progression:

> *"[W]hen they ask me something, it becomes less and less, 'Where is this chemical?', and more, 'We don't understand why this happens', or 'Do you think we should?'... Instead of just asking, 'What should we do?' they say, 'Would it be a good idea if we did this and that?' They start coming up with a solution themselves: 'We see this, should we leave it on the heat for an extra five minutes, or what do you think, what would help?'." (Instructor 1, 2023)*

The same instructor notices students' progression, mentioning, '[T]hey come up with more qualified questions and qualified possible answers to their questions' (Instructor 1, 2023). They described the interactions with students as becoming more sophisticated and more about the science itself, rather than about practical and technical elements of the laboratory work. Another instructor observes the students when handling instruments and makes a connection between a seemingly simple operation of using a pipette and abilities to do 'good' science.

> *"[M]any would say, well, it is not important that you can use that pipette correctly because that is what the lab technician does ... or what should I say... Or there isn't that, um ... um ... your cognitive level isn't that high there, or what should I say, but it's also what enables us to eventually do science that is precise and that we can trust, essentially, right?" (Instructor 4, 2023).*

Again, the instructor centres the practical skills and the handling of instruments in the learning process, but also emphasises learning to be about doing 'science that is precise' (Instructor 4, 2023). The instrument and learning to use it therefore plays a role in producing 'correct' knowledge and that is reflected in the instructors' recognition of precise ways of handling instruments. This connection becomes even more apparent when applying Polanyi's (1958/2002) *operational principle*, where the types of knowledge we obtain in the laboratory are expanded, especially when failures that are 'unexplained' (p. 329) happen. In *Personal Knowledge: Towards a Post-Critical Philosophy*, Michael Polanyi (1958/2002) discusses the difference between scientific and technical knowledge, and argues that when we encounter failures, we will need both *technical* and *scientific* knowledge to be able to solve the problem. Technical knowledge has an abstraction attached, an underlying operational principle that is uniquely technological and not scientific. Polanyi (1958/2002) explains, '(…)[A] tool, a machine or a technical process is characterized by an operational principle which differs altogether from an observational statement' (p. 328). An operational principle is connected to the purpose of the machine and is thus disconnected from science, 'a common operational principle cannot be even approximately specified in terms of physics and chemistry'' (p. 329) because the operational principle is connected to how the machine and its parts function. This also means that the operational principle of machines, the technical knowledge, say nothing about the failures as they are '*rules of rightness*, which account only for the successful working of machines but leave their failures entirely unexplained' (p. 329). On the other hand, pure scientific knowledge in, for example, physics and chemistry, 'would in itself not enable us to recognize a machine' (p. 330) and therefore not provide clues for how to solve a technical problem. Polanyi (1958/2002) infers that '(…)[T]he two kinds of knowledge, the technical and the scientific, largely by-pass each other' (p. 331). In the case of the teaching laboratory, students therefore need both technical and scientific knowledge, as well as tacit knowledge in order to solve problems and thereby show learning progression, which in turn is recognised by the instructor as being able to handle instruments 'correctly'. Polanyi (1958/2002) reasons that we can make use of scientific observations 'in order to deepen our understanding of a machine' and 'establish the material conditions under which the parts can *fulfil* their function and which will *explain* their occasional *failures'* (p. 331). This deepening of understanding is what instructors experience when they are in scientific discussions with students in the teaching laboratory. The instructors experience a change in students' ability to use scientific knowledge to understand the function of the machine, when they are able to explain mistakes, and solve the mistakes. This series of competencies is part of what instructors assign as evidence for learning progression. Importantly, this knowledge is both what students can achieve and what instructors gain access to while working with the students in the laboratory.

> *"It is about whether they can see when mistakes are made. The good students (…) they are the ones who can do troubleshooting when the experiments do not work, as they should. They go back and figure out, well if this does not work, where is the mistake? It can be in the theoretical, in the experimental, or in the solutions we have made" (Instructor 3, 2023).*

When instructors recognise students being able to solve problems and correct errors, it can be an expression of students being able to combine different kinds of knowledge according to the 'rules' of the discipline. Further, as Roehl (2012) points out, 'post-phenomenological accounts of materiality and practice point out that malfunctions and disturbances can be an opportunity for reflexively thinking about human conduct and the use of objects' (p. 119) and proposes that this provides an opportunity for educational research to observe and analyse learning situations. The instructors thereby use the 'malfunctions and disturbances' to observe students as they learn to solve their mistakes and this helps us to understand why instructors recognise problem solving as learning in the teaching laboratory (see Jørgensen et al. [2024] for an expansion of this). The task of problem solving points us towards a deeper understanding of how learning progression can be conceptualised, especially in relation to the work done in the laboratory, as this instructor highlighted: 'The experimental work should also help them develop a mind-set' (Instructor 3, 2023). The mistakes thus provide access to discuss science, as students need to go beyond explaining how something works and the instructor experiences those students become 'more capable of tracing back and figuring out what could have gone wrong' (Instructor 3, 2023).

Material agents and technological mediations in the laboratory

Instruments and technology are important in the teaching laboratory, where learning to use and handle tools is fundamental in order to access technical, scientific, and tacit knowledge. The post-phenomenological approaches create an analytical shift that helps us make some of the invisible interactions visible (Roehl, 2012). In the teaching laboratory, not only strictly laboratory instruments function as tools for teaching and learning. For example, one instructor stressed how the use of paper becomes an important tool in their interaction with students. Through the shared use of this tool, the instructor experiences that they can gain access to students' learning process:

> *"[T]he best tool in the laboratory is this piece of paper, because then we can jot it down, and we can discuss what should we write, and that's regardless of whether it's a concentration they can't figure out, or if it's more elaborate models, then we must start by jotting down. (...) [Then we] sort through the information we have, and [discuss] how we can then continue calculating" (Instructor 3, 2023).*

Here, paper becomes active in both the students' learning and in the instructors' possibilities for helping students in their learning process. The instructor explained how they can join the students' conversation or help to solve whichever problem they are facing. The paper is here a flexible tool that can support both practical and theoretical knowledge building. The instructor added:

> *"[S]ometimes you have the pleasure of seeing a spark in their eyes, when they say, 'Ah, that is it!', and then they can do it themselves. In the best-case scenario, they get a bit of graph paper, and then* they *lead the way while we are talking" (Instructor 3, 2023).*

In Karen Barad's concept of knowing-in-being (2007), instruments become agents that students learn with, though, and from. Both humans and non-humans, i.e., the paper, act as co-creators in the knowledge construction (Barad, 2010) and the focus on agential intra-action (Barad, 2003) provides a lens to seeing the role of material instruments:

> *"Apparatuses are constituted through particular practices that are perpetually open to rearrangements, rearticulations, and other reworkings. This is part of the creativity and difficulty of doing science: getting the instrumentation to work in a particular way for a particular purpose (which is always open to the possibility of being changed during the experiment as different insights are gained). Furthermore, any particular apparatus is always in the process of intra-acting with other apparatuses" (Barad, 2003, pp. 816–817).*

Barad points towards these rearrangements in the laboratory as situations where science becomes interesting and creative, although the openness of laboratory experiments is also challenging for students. The paper is here efficient in helping the students to 'take over' as they have received enough help to continue themselves. This is a small but very significant act, especially in a laboratory space that can be overwhelming to some students, as this instructor pointed out:

> *"[A few students] almost had nervous breakdowns from being in the laboratory, it was simply too stressful for them, mentally, in some way, you know. And what also happens is that there are a lot of people around you, and everyone talks, and depending on the type of group you have, sometimes there is a very high noise level" (Instructor 1, 2023).*

The concern of sensory overload in laboratory environments (Flaherty, 2022) is relevant here, as the instructor described these situations as hindering learning. The chaos created while being 'open to rearrangements', in Barad's words, or the creative process of doing science while being in an unfamiliar space with many people can be challenging for students. The impact on the learning environment prompts instructors to find tools to re-create an interpersonal space where they can support student learning. As a way of focusing on the task or the specific problem of a group of students, the pen and paper work as materials that instructors use to help students keep focused on their learning. The co-creation is visible in the case above, as the instructor described how they start out holding the pen, but in the 'best-case scenario' (Instructor 3, 2023) they hand over the pen to the students and they continue themselves. The paper supports student learning as well as giving the instructor access to the students' learning processes. The importance of this material is further recognisable by its absence. Here, the instructor explained how other materials, like tablets or computers, are more challenging, as they distract students from the co-creation:

> *"I have a challenge when I meet the students, and they either have nothing in their hands, (...) or they have a computer, they sure don't have any easy tools to work with" (Instructor 3, 2023).*

The notion of how humans and non-humans interact in the laboratory setting, and how a piece of paper becomes a technology for learning, is aligned with the argument for the inseparable nature of technology and humans. Peter-Paul Verbeek's (2005) theory of technological mediation directs us to think of instruments or technologies as not only in-between humans but also as active agents in shaping knowledge, who people are, the interactions between people, and the world around them. As technologies become more than physical objects distinct from human actors, the objects in the laboratory become agents facilitating the connections between humans and their environment; in this case, helping students construct knowledge while being in the laboratory.

Students' spatial moves in the disciplinary culture

In the instructors' discourse about learning progression, they consider how students move in the laboratory to be indicators for learning. For example, instructors notice in the beginning of a course how students focus on concrete objects, 'where are the materials and … how do I orient myself in this room' (Instructor 2, 2023). At the end of the course, 'they are all, to some extent, more self-reliant' (Instructor 2, 2023), and 'they sort of find their own way to be in the laboratory' (Instructor 1, 2023). As another instructor formulated it, 'they spend less effort on the practical things that are there and they also become better at assessing whether their things are going well or poorly' (Instructor 3, 2023). This shows how the students' focus changes as they become more familiar in the laboratory space and with the laboratory practices. This behavioural change can be seen as a natural development as students spend more time in the laboratory. With the theory of technological mediation (Verbeek, 2005) in mind, this is an expression of students becoming part of the laboratory environment, as technologies do not exist autonomously from their users and their functions; technology becomes part of humans being in the world. This is a way to see technology as something more than tools, meaning that student learning in the laboratory is not confined to being able to use the materials and instruments. It is also linked to a more substantial change in behaviour, as technologies become a part of their movement and of being in the laboratory. The ability to move more freely, interact in 'self-reliant' (Instructor 2, 2023) ways, or become 'better at conducting themselves in the laboratory' (Instructor 3, 2023) are examples of how instructors observe what they understand as learning progression. What they observe is a change of behaviour in students as they learn the laboratory space, and through the lens of technological mediation, the change of behaviour can be seen as a result of them learning with and through materials and technologies.

As the instructors described the spatiality of the laboratory, they often talked about the physical space (i.e., the moving about or being there) and the handling of instruments (i.e., improving pipetting skills). Space, though, has many dimensions and in Doreen Massey's (2005) construction of space, it is dynamic, with relations-between and always under construction. Space as embedded in 'material practices which have to be carried out, it is always in the process of being made' (Massey, 2005, p. 9). With this in mind, instructors and students are creating the learning space together as they co-occupy the teaching laboratory. The laboratory space is thus constructed including the interpersonal space, i.e., the interactions between students, and their questions, in combination with the physical space. This perspective adds another layer to the interactions in the teaching laboratory, as the construction of the space is not predetermined by the materials and the physical space but as an active dynamic process between humans and the materiality. This lends a variety of interpretations of how to understand learning progressions as students learn 'to conduct themselves' (Instructor 3, 2023), as noted above. From the perspective of relational spaces, the interpretation needs to include a sensitivity to students being directed by the instructors as well as to the role of materials in the laboratory. When connecting this to instructors' ideas about an 'ideal' student, we see how both educational spaces and the instructors direct students towards an imaginary of how to perform (Wong and Chiu, 2020). How this influences student learning outcomes is in this case speculative. However, from a socio-cultural stance, these observations call for a recognition that what we observe is influenced by experience, our attitudes, identities, values, and the disciplinary culture that instructors are part of. For example, what is it this instructor observes as learning progression and why?

> *"The [students] become more courageous (...). I feel a development happening during the course, and this I find important: they learn to talk in a scientific way and discuss science and they become more comfortable with being insecure" (Instructor 4, 2023).*

This instructor put into words some of the subtle changes in student behaviour they observe. By highlighting students' attitudes or expressions, like becoming 'more courageous' or 'more comfortable with being insecure', this instructor expanded on learning progression from being about individual knowledge production to including ways of being or approaching the practical work in the laboratory. This is an important observation that shows how subtle changes in language, as well as explicit actions like handling instruments correctly, play a role in instructors' construction of student learning. The instructor also linked learning progression to how students 'learn to talk in a scientific way'. Günter et al. (2023) show how instructors' discourses of student learning are shaped by intersections of their own roles and identities as researchers and instructors. The authors furthermore report an awareness in instructors about research and science-related identities being valued more than a teaching identity. This performance of science and research competence risks getting translated into recognising only those students who act in line with science and research discourses, like those that 'talk science'. Wong and Chiu (2020) also discuss the pitfalls of stereotyping students and find that instructors' constructs of the ideal student 'were remarkably similar to how academics themselves have conceptualised the "excellent" university teacher' (p. 62). This prompts us to reflect on what we observe, how we evaluate students' questions, or what we notice when 'seeing a spark in their eyes'. This includes recognising that our own disciplinary identity and the academic culture we are part of (among many factors), have shaped us and thus shape our understanding of what a 'good student' is and how we are able to recognise students as competent.

Discussion

This exploration of learning progression in the teaching laboratory is a humble one; as a small-scale study, it only renders results for further reflections. The openness of the inquiry made it possible to explore the nuances of instructors' discourses about learning in the laboratory as well as some of the underlying implicit ideas about students and their learning. This accounts for the complexity of what learning progression means in a laboratory environment, and of how interactions with materials and uses of instruments are important for our perception of learning. The analysis shows how instructors in this environment use observations of behavioural change (e.g., asking questions, solving problems) and changes in how students move in the laboratory as a proxy for learning progression. Research on learning progression uses various methods on multiple scales and therefore varies greatly in their ability to provide generalisable results. To mention a few, Humburg and van der Velden (2015) show a need for sensitivity to cross-national differences in a large-scale survey studies, Ramberg et al. (2021) advocate for a diverse use of measures to capture students' knowledge progression, and Jørgensen et al. (2024) show how instructors and students in the same programme conceptualise learning progression in different ways. With the aim of exploring how students' learning progression is conceptualised by instructors in the teaching laboratory, this study adds a socio-material and socio-cultural perspective to discuss how we might expand our understanding of learning progression to go beyond surveys and rubrics. To this aim, observations of instructors and students in a teaching laboratory would provide additional insights.

In relation to students' ability to work with mistakes, the analysis shows how mistakes are used by the instructors to approach students' learning of scientific concepts, as they provide possibilities to discuss science and deepen students' understanding of the laboratory experiment. This is important because mistakes both become a sign of learning progression, as formulated by instructors, as well as feeding into a didactical argument for designing laboratory teaching with an openness to, and curiosity towards, mistakes. Moreover, it points towards the importance of having enough time to discuss scientific concepts with students in order to surpass the technical knowledge of machines and experiments. However, providing more discussion time in the laboratory needs to be accompanied with setting clear expectations as to how and what students should spend the time on as well as pedagogical strategies for instructors, e.g. how simple tools like pen and paper can assist in the interaction between instructor and students. Research on student learning in laboratories shows a tendency for some students to focus on becoming as efficient as possible (DeKorver and Towns, 2016), influencing how they work with laboratory assignments (Finne et al., 2023), and ultimately how they learn science.

Naturally, the attempt to analyse cultural and socio-material entanglements through discourse analysis presents a dilemma for this study. While the socio-cultural analysis needs the discursive analysis, the socio-material analysis aims to centre the materiality and precisely give human discourse a smaller role. This creates the inherent dilemma that both analyses are entangled and dependent on each other but at the same time exclude each other. Yet, it is precisely in this intersection that the analysis of instructors' discourses about student learning in the laboratory is both made possible and provides new perspectives.

Conclusion

This study explored instructors' discourses of learning progression in the teaching laboratory. The study argued for considering the socio-material affordances of the teaching laboratory as well as the socio-cultural context. By bringing together a theoretical framework with tacit knowing, materiality, co-creation, and technological mediations, the analysis offered a nuancing of instructors' discourses that challenges the assumptions that learning progression is impossible to recognise. The analysis showed instructors identify learning progression through observing students improving their laboratory skills, in dialogue with students (i.e., when asking questions and explaining mistakes), as they work on a shared problem, and through observations of how students move in the laboratory space.

The observed behavioural change in students is interpreted as an expression of students becoming part of the laboratory environment, as they learn with and from the materials and technology surrounding them. By seeing though the technology as simply technological tools, it is possible to nuance what student learning in the laboratory means, avoiding the risk of reducing learning to being able to use materials and instruments. Instead, instructors conceptualise the change in behaviour as a proxy for learning progression, as technologies become a part of their movement and being in the laboratory. Simultaneously, the study problematised how instructors' observations of students' learning are influenced by their own perceptions of what a 'good student' is, which is especially sensitive in this space, where instructors rely on their observations and interactions with the students.

By exploring learning progression in the intersection of the socio-cultural and socio-material of the teaching laboratory, the study offered insights into the entanglements of students learning with and from materialities and technologies in the laboratory space for further critical reflections in higher education.

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Acknowledgements

Thank you to the instructors who took the time to introduce me to their laboratory teaching practices. Thank you, Marie Larsen Ryberg, for feedback on early editions of the manuscript, and Katerina Pia Günter, for feedback in the final stage. To the two supportive and helpful reviewers, thank you for seeing the work and helping me think. The work presented in this article was supported by the Novo Nordisk Foundation, Grant NNF 18SA0034990. The foundation had no involvement in the research conducted or the preparation of this article.