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"I don't know, ask the chemists – I think it's kind of a consensus among them" – Information practice in a problem-based beginner lab

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Abstract: Information literacy is increasingly acknowledged as a contextual and social practice in teaching and research and can be beneficial to further our understanding of laboratory learning. However, there is a need for in-depth insight into the lived information practice in chemistry to develop contextualized information literacy instruction. This work explores the negotiation of information between beginners and experienced members of the chemistry community in a problem-based beginner laboratory. To this end, we conducted a qualitative study following the documentary method by audio-recording the students' first lab session on-site. The reconstruction of the students' information practice shows how beginners learn about group-specific knowledge through participation. The results highlight the importance of corporeal information to give meaning to textual and social information in the chemistry laboratory. Exemplified by the concept of acidification, our findings show how social and textual information alone is insufficient for beginner students' understanding of tacit information. Physical experience and social guidance are necessary to develop shared conceptions between people in the chemistry laboratory practice. Beginner laboratory instruction could benefit from this work's results by teaching beginners about the corporeal, social, and textual information modalities and showing how they connect in practice.

Keywords: communities of practice; higher education; laboratory work; problem solving.

1 Introduction

Research unveiling educational shortcomings of expository laboratory practicals has given way to the increasing implementation of nontraditional laboratory concepts (Di Fuccia et al., 2012; Eilks & Byers, 2010) such as problem-based learning (PBL) (Raker et al., 2021; Sandi-Urena et al., 2011). PBL "empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (Savery, 2006). In a chemistry PBL lab, students are responsible for designing the experimental procedure, and the experiment becomes a means for problem-solving (Eilks & Byers, 2010; McDonnell et al., 2007). However, non-traditional lab formats, such as PBL labs, also present new challenges that are yet to be understood by research (Keen & Sevian, 2022).

In a beginner laboratory, students experience a new, complex learning environment (Seery et al., 2019). Unfamiliarity with non-traditional lab concepts and the addition of implicit expectations can cause "a general state of confusion" (Chopra et al., 2017). The learning scenario in the laboratory is "complex, collaborative, and context dependent" (Keen & Sevian, 2022) and is determined mainly by human interaction (Jobér, 2017). Thus, Keen and Sevian (2022) adopted a sociocultural framework to examine students' struggles in the undergraduate

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chemistry laboratory. The authors suggested characterizing the students' struggles in the laboratory into four domains – cognitive, psychomotor, epistemological and socioemotional – comprising a domains-of-struggle framework.

However, more research is needed to gain a better understanding of the beginner PBL laboratory as a complex learning environment. As students enter the lab, they learn to engage with textual, social, and physical information in specific ways that are sanctioned by experienced group members. It is worth noting that the physical experience in the laboratory is linked to learning beyond isolated "psychomotor" or "practical skills" (DeKorver & Towns, 2015; Flaherty et al., 2017; Hofstein, 2004; Keen & Sevian, 2022).

To complement the aforementioned findings on laboratory learning, this article analyzes students' experience of entering the laboratory as a new community of practice by examining it through an information literacy practice lens. By exploring their engagement with information, we can gain insights into how beginner students learn and how we can best support them. This approach addresses one of the "important questions" identified by Hofstein and Lunetta (1982) namely "What is the student really doing in the laboratory?" (Hofstein & Lunetta, 1982).

Information literacy in this work is defined after Lloyd (2010a) "as a sociocultural practice that facilitates knowledge of information sources within an environment and an understanding of how these sources and the activities used to access them is constructed through discourse. Information literacy is constituted through the connections that exist between people, artifacts, texts and bodily experiences that enable individuals to develop both subjective and intersubjective positions" (Lloyd, 2010b). Figure 1 shows the information modalities relevant for information literacy based on a model by Lloyd (2007) that is adjusted to chemistry practice (Lloyd, 2007).

The particular ways of engaging with social, textual and corporeal information in a PBL beginner lab are examined in this work by adapting a documentary methodology (Bohnsack, 2010). The intent is to explore in detail students' experiences when they first enter the lab. To this end, the student and teaching assistant (TA) discourse of the first laboratory session serves as a discourse between a new member and an experienced practice member.

1.1 Information literacy as a social practice

Information literacy has been theoretically framed as a social practice for almost 30 years (Hjørland & Albrechtsen, 1995; Rath, 2022). How information is acquired, shared, valued and transmitted to newcomers depends on the particular community and its participants (e.g., nurses, librarians, firefighters) (Lloyd, 2021). Despite extensive discussion of these developments in the scholarly literature (Cox, 2012; Head et al., 2013; Lloyd, 2010a; Todd, 2017; Tuominen et al., 2005), there is still a lack of understanding of how information literacy

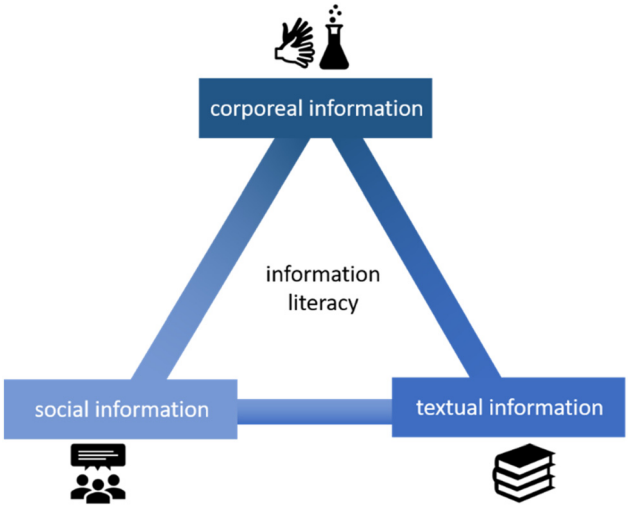

Figure 1: Information modalities relevant to chemistry practice based on the information literacy model from Lloyd (2007).

functions as a social practice in the context of chemistry education. However, exploring information literacy as a social practice could lead to a better understanding of laboratory learning.

Lloyd (2010a) draws on Schatzki's site ontology (2002) to explain the theoretical framing of information literacy as information practice (Lloyd, 2010a). This framing views practice as the central feature of social life, where knowledge is situated locally and is the result of collective, embodied, and informed work within a specific space, such as a workplace, school, or chemistry laboratory (Ibid.). To make sense of information in a given context, one needs the experience of authentic practice (Lloyd, 2007). Therefore, Lloyd suggests that researchers should focus on the sociocultural affordances of practice as the unit of analysis for studying information literacy, rather than information skills. This is because these affordances lead to the development of information skills (Lloyd, 2010b), which is a widely acknowledged attribute in the literature (Association of College and Research Libraries, 2015; Hosier, 2019; Rath, 2022).

The framework of workplace-related information practice is particularly relevant to the chemistry laboratory, given the many similarities between laboratory practice and workplace practice: "In workplaces where there is an emphasis on practical and embodied understandings and more value placed on experiential knowledge and know-how, information literacy will reflect the informal nature of learning within site" (Lloyd, 2010a). Professional practice requires more than the application of theoretical knowledge, and involves "knowing-in-practice," which is characterized by developing knowledge collectively and in an ongoing way in response to specific situations (Price et al., 2020). The literature also emphasizes the importance of social sharing of information between experienced and novice practitioners, which provides a useful theoretical frame for this study's intent (Brown & Duguid, 1991; Wenger-Trayner, 2008). As beginners interact with community members, they decode the "sayings of practice" and eventually become equal members by establishing a shared understanding (Lloyd, 2010a).

Novice practitioners encounter both explicit and tacit knowledge in the chemistry laboratory. Explicit knowledge is expressed through codified rules, lab manuals, textbooks, and written and verbalized guidelines (Lloyd, 2010a). In contrast, tacit knowledge refers to knowledge that cannot be fully expressed by the subject, such as flexible processes of perceiving, evaluating, expecting, thinking, deciding, or acting (Porschen, 2008).

Kirschner (1992) argued that one central aim of laboratory practicals in education is to accumulate tacit knowledge through experiencing scientific phenomena. This involves obtaining an implicit, often indescribable, feeling for what is happening or what is supposed to happen, rather than explicit knowledge of how something works or why it works (Kirschner, 1992). Keen and Sevian (2022) also highlighted the importance of rules and routines in the laboratory, as they are how the community and participants implicitly and explicitly negotiate their beliefs about the structure, content, and process of learning chemistry " (Keen & Sevian, 2022) This work aims to explore how the experience of scientific phenomena and the experience of rules and routines contribute to the information practice of students in the laboratory. It highlights the importance of both explicit and tacit knowledge, as well as the embodied aspects of information practice, for effective learning.

The following research question guides the study:

How is information practice represented and developed in a problem-based beginner laboratory?

2 Methods

In this study, the documentary method was the method of choice to explore the different characteristics of information practice in the chemistry beginner lab because it enables empirical access to group practice (Bohnsack, 2013). The documentary method is an approach of reconstructive social research that explores how social reality is constructed (Bohnsack, 1999) and is based on the epistemological and methodological foundation of Karl Mannheim's sociology of knowledge (Bohnsack, 2017). Mannheim provides a framework of conjunctive spaces of experience that are characterized by their members sharing common structures of experience and knowledge (In Mannheim, 2003). Conjunctive spaces of experience describe how people are connected by common existential backgrounds, i.e., that they understand each other directly due to a common background, and can, thus, articulate themselves as if they were attuned to each other (Bohnsack et al., 2013). The conjunctive nature of language in specific experiential spaces constructs a shared understanding of meaning and a way of handling things that is specific to the group (In Mannheim, 2003).

The social science interpreters, in the sense of Karl Mannheim's sociology of knowledge, do not assume that they know more than the study subjects, but rather the latter, themselves, do not know what they actually know, and, thus, have implicit knowledge that is not readily accessible to them (Bohnsack et al., 2013). This implicit knowledge emerges in conjunctive experiential spaces and is documented in the "how" of social actions and discourse (Ibid.). It is the task of the researcher to explicate this implicit knowledge to understand practice: "It is the change from the question *what* social reality is in the perspective of the actors, to the question *how* this reality is produced or accomplished in these actors' everyday practice. By practice, I mean the practice of action as well as of talk, of presentation and of argumentation" (Bohnsack, 2010).

By asking *how* the practice is constructed yields the reconstruction of the organizational principles of the conjunctive spaces of experience (orientations) that are the implicit action-guiding nature. The distinct steps of data analysis in the documentary method will be further elaborated in the section "Data collection and analysis."

Usually, the documentary method uses group discussions for data collection. However, the aim is to keep the discourse situation as authentic as possible (Meyer & Verl, 2019). In this study, the information practice in the laboratory was of interest, therefore, there was no need to create an artificial interview setting. Instead, the first lab session of two groups of students was recorded on-site. The approach is described in the following section.

2.1 Setting and participants

This study was conducted in a problem-based learning lab at Goethe-University Frankfurt, Germany. Due to the focus of the study is the information practice of beginners, we chose the first lab session of two groups of non-major chemistry students for data collection.

The students participated in the problem-based lab course in line with a general inorganic chemistry module for non-majors. The participants' names were substituted with pseudonyms to protect confidentiality. All the students majored in earth sciences, between 19 and 22 years old, and had a mandatory general inorganic chemistry module in their bachelor studies. They worked together in groups on the problems posed in the PBL laboratory concept for four weeks in August 2020, with lab sessions once every week for approximately 5 h. The division of the groups was left to the students. In total, 12 students participated in the laboratory course, resulting in three different groups. The two groups selected for this study were chosen because they were not taught by one of the authors. The third group, however, was instructed by one of the authors and it was therefore excluded from the analysis. The two groups consisting of seven students and their teaching assistants gave informed consent to have their first lab session audio recorded. Table 1 gives an overview of the participants.

In group A, Johannes and Arne were in the second semester when attending the lab course, while Jakob was in the sixth semester. All the students that participated in group B were in the second semester. This was the first chemistry lab practical for all students. The teaching assistant, Jana, had studied chemistry to become a teacher and had already completed her first state exam. The second teaching assistant, Carina, was a postgraduate chemistry major thus, both Jana and Carina had extensive laboratory experience, however, they did not have any previous laboratory teaching experience as TAs. Ben was an additional supervisor working for the institute who alternated between both groups and who had long-standing teaching experience in supervising different laboratory practicals.

On the one hand, the undergraduate students were all newcomers to the chemistry lab, while, on the other hand, according to their education and experience, Jana, Carina and Ben were considered experienced members of the chemistry community. Therefore, the sampling was deemed suitable for the current study in further comprehending the representation and development of an information practice as well as the role of tacit knowledge in the chemistry lab.

2.2 Lab activity

The lab activity focused on industrial lithium extraction from brine, providing an authentic problem for introductory chemistry students to address basic chemical concepts and laboratory techniques. The experiments involved classic detection reactions and current analytical methods, and students are instructed as if they were employees of an industrial company. Details about the problem-based laboratory concept, the problem design and implementation have already been published (Wellhöfer & Lühken, 2022b). The problems are small-step extensions of known material.

Table 1: Overview of participants.

	Group A	**Group B**
1	Johannes	Florian
2	Jakob	Frederik
3	Arne	Marie
4		Philipp
TA	Jana + Ben	Carina + Ben

The study was set up around the first problem: "Analysis of an unknown salt mixture". For the first problem, the students analyze an unknown salt mixture and determine which ions their sample included. The problem concerned a qualitative sample analysis that included a possible limited number of ions. It was designed as an introduction to the problem-based concept and is, thus, suitable for the current study in understanding the students' first-time practical experiences in the laboratory.

2.3 Data collection and analysis

The data for this study stems from the audio recordings of the first lab session of groups A and B. Both lab sessions yielded around 4 h of group discourse and were transcribed verbatim. Initially, following the documentary method, the transcribed dialogs were thematically structured according to their relevance to the research question (Bohnsack et al., 2013). Subsequently, sections relevant to the information practice were identified.

Selected for the interpretation were certain text sections that had a particular narrative or interactive density (Bohnsack et al., 2013). These sections were identified by looking for linguistic patterns, such as the group's interaction patterns, including the frequency of two-person exchanges, simultaneous speaking, and extended periods of silence. Additionally, sections were selected with a notably high number of questions asked. It can be assumed that these sections contained important aspects related to the participants own experiences as well their information practice (Kleemann et al., 2009). Based on these criteria, linguistically significant passages were identified and analyzed, seeking out thematically similar passages for comparison. The analysis was started with Group A's transcript, identifying themes related to acidification, disposal, and safety, and then comparable themes in Group B's transcript were identified. As this interactive density was predominantly found in the transcript of group A, this group yielded more passages which were selected for interpretation.

The interpretation of the identified sections involves two steps: formulating interpretation and reflective interpretation. The formulating interpretation is concerned with the immanent, literal meaning, which asks the question, "what?" It considers the literal content of what the study's subjects expressed and is rephrased by the researcher. In the second step, the researcher provides reflective interpretations about the implicit knowledge of the study's participants (Nohl, 2005). This marks the switch from "what" to "how." In this study, the reflective interpretation was used to uncover the conjunctive knowledge of the group. It consisted of interpreting how the study participants dealt with situations and problems around the topics of acidification, safety, and disposal. The specific way of dealing with a problem is made visible by contrasting how, in other situations or groups, the course is set differently in the treatment of a comparable topic (Bohnsack, 2013). Orientation patterns are carved out by comparative analysis through different cases inside thematically similar topics (Ibid.). Tables that include the selected passages, formulating interpretation, and reflective interpretation for the named topics can be found in the Supporting information Table S1: Safety, Table S2: Disposal, Table S3: Acidification.

The authors first worked individually on the formulating interpretation and the reflective interpretation. Afterward, they gathered for several debriefing sessions to discuss the resulting tables and develop a shared analysis. The debriefing sessions and the collaborative work add credibility and dependability to the analysis (Hadi & José Closs, 2016; Shenton, 2004).

3 Results and discussion

This study examines the information practice in a chemistry beginner laboratory using the documentary method; this provides "access to the structure of action and orientation." (Bohnsack, 2010) The representation of the information practice in the case of explicit information is depicted in the next sections, using the topics of safety and disposal. The role of tacit and corporeal information is illustrated in the subsequent section using the topic of acidification.

Drawing on the topics of safety, disposal and acidification, key aspects of the representation and development of the information literacy practice were analyzed. All these topics have a common feature namely, that they exemplify group-specific knowledge (Kleemann et al., 2009). The themes are discussed using anchor examples presented according to the original chronological course of the conversation. All selected passages incorporated into the analysis are presented in the supporting information as tables, including the formulating and reflective interpretations (see Table S1: Safety, Table S2: Disposal, Table S3: Acidification).

The results show that the students need action-guiding social information from an experienced member in addition to textual information. Similar results were reported by Keen and Sevian (2022) who stated a common example in their study in which "students could not move forward without information from the TA or without the TA checking their work" (Keen & Sevian, 2022).

Practice requires the students to develop situational agency in different scenarios, it requires of them to "know-in-practice" (Reich et al., 2014). In order to develop "knowing-in-practice" concerning safety and disposal, students need to physically experience different lived scenarios. We illustrated the critical results in a model of

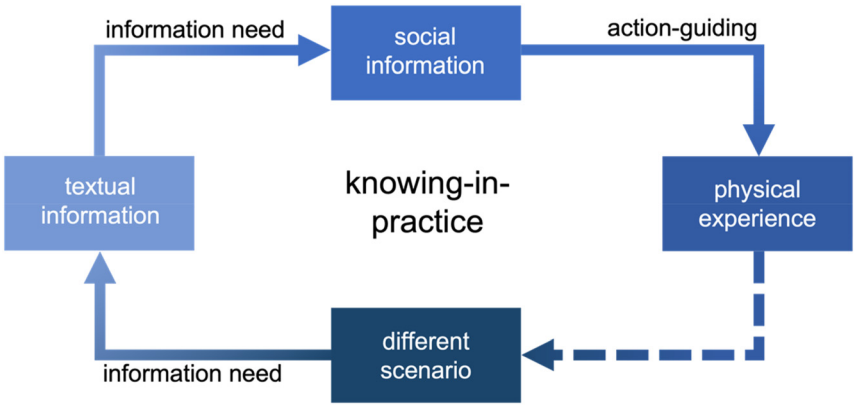

Figure 2: Illustration of the students' information practice in a problem-based beginner lab.

the students' information practice in the PBL beginner laboratory (Figure 2). The model displays the main results of this study and does not aim at representing the total of students' information practices, which would be too complex to be displayed in a procedural model. However, the model is helpful to support understanding of the main results of this study and the importance of social and physical information for chemistry laboratory learning. All the data that were used to develop this model are available in Tables S1 and S2. The following section gives a brief description of the model with examples from the data. It will be further elaborated, in detail, in the upcoming sections.

The model begins with a scenario in a problem-based beginner laboratory that triggers an information need (as indicated in the "different scenario" box at the bottom). In this study, when students encountered a scenario related to disposal or safety, the laboratory guidelines and teaching assistants expected them to have prior knowledge of the procedures. To meet this requirement, students initially researched the necessary information in textual sources to design their experimental procedures prior to the laboratory sessions. In the following case where a disposal strategy was missing, Jakob conducted further research in textual sources to address the information need:

> Jakob: "And the titan yellow and the Magneson I have to take a quick look at now."

This starting point, where the students need to research textual information for their problems, is due to the problem-based learning approach. Since they do not receive an experimental procedure, they have to look it up, initially by using textual resources (Wellhöfer & Lühken, 2022a).

In practice, the textual information was frequently not sufficient. In the following example in a conversation between Jakob and Jana, the information need is not met in the textual information:

> Jakob: "That's strange."
>
> Johannes: "What's strange?"
>
> Jakob: "It says here: Notes on disposal. Under waste treatment methods it says no further information available. Does that mean it's not dangerous or-?"
>
> Jana: "At Magneson or what?"
>
> Jakob: "Yes."
>
> Jana: "That no further-."
>
> Jakob: "It just says that there is no information."
>
> Jana: "Then you can put it down the drain."

Jakob cannot find textual information for his attempt to dispose of his sample. An information need arises that is met by Jana who provides action-guiding social information (Jana: “Then you can put it down the drain.”).

The next example shows again how the lived scenarios can be so versatile, that in practice, an information need arises that requires social information. Johannes explains to Jana the amount of barium contained in his sample. Jana explains to him that he does not have to dispose of this sample separately in the heavy metal waste container:

> Johannes: “That’s six drops of barium and that was 0.5 mol per liter.”
>
> Jana: “Then you don’t have to pour it in there (note: the heavy metal waste) again.”

Despite the clear disposal guidelines for heavy metals, Jana instructs Johannes to not dispose of the solution as heavy metal waste. This example shows how Jana, as a source of action-guiding, social information, is needed to decide how, exactly, one must dispose of the waste in each situation.

This social guidance was also necessary for reassurance in the next example. Arne expresses that he cannot dispose of barium hydroxide solution down the drain because barium has to be disposed of separately. Jana confirms Arne’s assessment of the situation:

> Arne: “If now for example, – if I now have barium hydroxide solution, I can’t dilute it with this acid and then tip it down the drain. That doesn’t work because barium is a heavy metal.”
>
> Jana: “With barium, exactly, that doesn’t fit. That’s right.”

After receiving the action-guiding social information, the students act; in this case, they dispose of the waste (physical experience). Following the physical experience, a new scenario occurs. By repeating this cycle, according to the model, the students will continue to develop their ability to make decisions on their own, they develop “knowing-in-practice” (Reich et al., 2014). The dotted line in the model in Figure 2 indicates that it is an ongoing process for the students to develop knowing-in-practice. The following sections clarify the model further, specifically underlining how the information practice materializes through the action structure.

3.1 “So is it OK to tip it away after neutralization or what?” – reconstructing the materialization of information practice

The following section will draw on the topic of disposal to reconstruct how the information practice materializes. Practice is dependent on the situation and is required to adapt previously acquired knowledge to a variety of situations that are not anticipated by the students in advance through theoretical preparation. In the following example, Johannes asks about specific ways to dispose of pH paper.

> Johannes: “These pH samples, do you have to dispose of them in a certain way?”
>
> Jana: “Do you mean the acid solutions or what?”
>
> Johannes: “No, I mean the paper samples.”
>
> Jana: “The snippets?”
>
> Johannes: “Yes.”
>
> Jana: “You can-, you can do that in a way that you-. Do you have paper towels with you, or?”
>
> Jakob: “There’s toilet paper up there.”

Jana: "Okay. Then you just take toilet paper like that, lay it out and then you can always let the pH strips dry. Okay. And then when they're dry, you can just throw them in the solid waste trash can and that's it."

Johannes asks if there is a "certain way" to dispose of the pH paper scraps. He does not formulate an idea of how to dispose of the pH paper scraps and asks directly. Nevertheless, his formulation shows that he has already learned that there are certain ways of disposal, certain "doings of practice" (Lloyd, 2010a). While the students have prepared for the disposal of chemical and material waste, the procedure in practice, which Jana demonstrates to them by letting the pH strips dry "like that" on the toilet paper, is not something that they have prepared for theoretically. Jana provides instructions on how to dispose of the paper snippets without explaining why it is necessary to dry them and dispose of them in solid waste. This example again highlights the need for social information in practice. When learning in practice, there are situations in which the TA guides procedures that the students in the theoretical preparation would not have anticipated. Becoming an equal member and making self-sufficient decisions in the laboratory means learning the ways of practice that the other members of the practice legitimize.

This situation of pH sample disposal is exemplary for disposal practice in chemistry because, although one would like to think so, it is not always possible to deduce from theory how to handle disposal in practice situationally. Instead, disposal situations are handled by responding to the situation at hand and considering guiding principles, depending on the subject's own socialization into the community of practice.

The following scenario further exemplifies the disposal in practice when Johannes asks Jana how he should dispose of the remains of silver nitrate in his pipette:

Johannes: "So I have a pipette here with silver nitrate."

Jana: "The other way around."

Johannes: "I see. Yes, I have … I assume that has to be disposed of in heavy metal, right?"

Jana: "Silver nitrate. Do you have anything else in there or what?"

Johannes: "There is no more liquid in it. But there are remnants of silver."

Jana: "Just rinse it out. That's-, well, it's minimal only. You can rinse it once, there is no liquid left."

Johannes has a suggestion for making a situational decision based on his theoretical knowledge of heavy metal disposal. He assesses the situation but still needs validation by an experienced member of the practice community. Jana tells Johannes how to "just rinse it out" and explains why ("there is no more liquid"). Johannes does not question her suggestion.

Keen and Sevian (2022) describes a similar situation in which the students experience epistemological struggles "when the lab procedure asked students to go against a lab norm," e.g., throwing waste into the sink instead of in the chemical waste garbage can (Keen & Sevian, 2022). Again, this is an example of the student's socialization into practice; they learn to handle these situations through social guidance and physically lived experiences.

In the further course of the session, the students proceed to discuss among themselves how they should proceed with the disposal:

Johannes: "Where do you keep the heavy metal stuff?"

Arne: "Here, with me."

Johannes: "Should I throw it in there? Yes, right."

Arne: "What if something emerges. *laughs* It will end up exploding, who knows."

At this point, the students know about the disposal procedure in theory and from previous situations in the lab and linked conversations. During the lab session, Johannes's knowledge about his waste belonging to heavy metal waste becomes repeatedly evident (see Table S2: Disposal). Nevertheless, he now looks to Arne for action-guiding social information who answers, "It will end up exploding, who knows," meaning he does not actually know. Despite the remaining uncertainty, the students can act without their supervisor and dispose of their waste. Keen and Sevian (2022) described socioemotional struggles in their study of students' struggles in a beginner lab and found that "often times, students moved forward as long as their emotional struggle was acknowledged" (Keen & Sevian, 2022). In our example, the social interaction was needed for reassurance and sharing the responsibility of making a decision. Even though the students did not ask the TA, they did ask each other. Thus, the students gain experience through action and negotiation, and eventually learn to make situational decisions independently.

These examples reveal different manifestations of the development of the students' information practice. They develop from, initially, asking the supervisor directly without actionable suggestions to then asking for feedback on suggestions and to group discussions between peers resulting in action.

The results exemplify how information practice is represented and developed in a chemistry beginner laboratory and the different characteristics it can exhibit in experienced community members and complete novices who are entering a new community of practice. The following section will discuss the structure of action in a beginner lab with regard to the group-specific importance of general guidelines in the case of safety measures, looking at the instruction in more depth.

"Always go into the fume hood with sulfuric acid." – Situational decisions and general guidelines for safety

The following section discusses the application of general guidelines to information practice exemplified by safety measures. The situational application of general guidelines can provide indications of the group-specific socialization in the laboratory environment. The cases of situational hazard assessments referring to guiding principles illustrate how information practice is both subjective and intersubjective (Lloyd, 2007). In the following example, Jakob and Jana discuss whether Jakob should use one drop of one molar sulfuric acid in the fume hood.

> Jakob: "With 1 mol per liter sulfuric acid, I don't have to go into fume hood, right? *laughs* Or even then?"
>
> Jana: "Now, if you take a drop of-."
>
> Jakob: "One drop …"
>
> Jana: "You could maybe take a fume hood once or something."
>
> Jakob: "Okay. That is, put the thing in the fume hood, then?"
>
> Jana: "If something tips over there by accident, then you have the fume hood, then you're safe. With sulfuric acid always go into the fume hood."
>
> Jakob: "Okay. Good."
>
> Jana: "Just take that over here in fume hood."

Jakob finds the idea of going into the fume hood with one molar sulfuric acid amusing and absurd, therefore, he laughs and asks the question in a manner that shows he expected a "no" as an answer. However, even though Jakob feels competent to propose this situational assessment for the practice, he does not act independently. Here, Jakob's participation in the practice community is documented; he applies and adapts his theoretical knowledge to practice, which, however, still needs corroboration (social guidance). Nevertheless, his formulation clarifies that he has assessed the application of safety measurements and is not "just" asking (Jakob: "With 1 mol per liter sulfuric acid, I don't have to go into fume hood, right?"). In theory, Johannes knows to use the fume hood when

working with sulfuric acid, but his knowledge becomes meaningful only when he learns to adapt it to practice, where one nuanced situation always differs from another (Elmborg, 2006; Reich et al., 2014). He needs social information, that is action-guiding from Jana.

Jana cautiously disagrees, suggesting that Jakob "could maybe take the fume hood or something." Even though Jakob does not question the proposal, Jana explains: "If something tips over. Always go into the fume hood with sulfuric acid." She refers to a guiding principle she knows to support her instruction. The initially cautious suggestion to go into the fume hood becomes a general statement. Jana's formulation, "With sulfuric acid, always go into the fume hood," suggests that she bases her instruction on a guiding principle that she, herself, learnt in practice. Jana's guiding principle of to always use sulfuric acid in the fume hood is explained by her because the acid could tip over; the fact that other acids could also tip over and cause severe damage is not of consideration at this point. The guiding principle from Jana stands in contrast to Jakob's initial situational hazard evaluation and idea for action. Jakob accepts the suggestion without questioning it.

Safety is of crucial importance in a chemistry laboratory. The use of guiding principles in a variety of situations highlights different characteristics of chemistry information practice. Considering safety, the supervisor might act out of their responsibility according to the motto "safety first" and refers to higher-order rules that they learnt in practice. The supervisor applies general conventions which correspond to a higher safety standard.

In the following example, the supervisor intervenes and advises Arne against using gloves. They contradict the student's theoretical preparation and their subsequent safety concept.

> Jana: "Why do you need gloves for this?"
>
> Arne: "Because of barium hydroxide solution?"
>
> Jana: "Well…"
>
> Arne: "No, fuck it, I don't care. I was just-."
>
> Jana: "You have to-, I wanted to ask again anyway, why, for what you need gloves, in general, when you-."
>
> Arne: "For acids in any case?"
>
> Jana: "If you take the instructions very seriously. But a little bit of acid, in such a small amount, should also-. Just work concentrated. On your bases anyway, that you don't spill anything, okay? If something should get on your hand, rinse off directly. And with sulfuric acid generally in the fume hood …. It's very – okay."

The conversation shows how Arne interprets Jana's question and her answer "Well … " as a rejection of the gloves he uses. His response to her rejection of the gloves, "No, fuck it, I don't care," depicts how keen he is to follow Jana's suggestions, again, without an explanation. Jana's instruction is a general rejection of gloves in this laboratory context. This is evident from the way she phrases the question, "What do you need gloves for in general," and her subsequent comment, "Just work concentrated (…) If something should get on your hand, rinse off directly." She is not just referring to this situation, but to a guiding principle about when or when not to use gloves. Although the dialog is only between her and Arne, she uses the German plural "you" and addresses all the students which emphasizes the generality of her statement. A similar situation occurred in the other lab where Ben also advised students not to use gloves (see Table S1: Safety). However, Ben explained that his suggestion was for safety reasons; the students might accidentally touch their faces or other vessels with dirty gloves. Jana makes no such explanation. An explanation was not a requirement for the students to accept these guiding principles.

Differences in the instruction by the TAs and subsequent differences in the meaningful use of learning situations have been reported in the literature (Huffmyer & Lemus, 2019; O'Neal et al., 2007). In this study, the difference in instruction by TAs was particularly evident in relation to "the sayings and doings of practice" (Lloyd, 2010a), and how they were sometimes passed on without explanation and unquestioned. The findings suggest that this may be related to the information practice in the laboratory. The way students accept all social information from the TA, with or without explanation, could indicate the socialization in this setting. Some of these students

will become TAs, thus, the present TAs were once students. The sharing of these guiding principles could indicate how Jana herself learned about them when she was a newcomer in the laboratory practice.

In the case of both Ben and Jana, the students accepted their suggestion not to use gloves without question. The use of general guidelines contributes to the socialization of students in this community of practice and provides a specific framework. This framework allows situations and action decisions to be clustered (no gloves, always go into the fume hood with sulfuric acid). The unquestioned transmission of rules of conduct illustrates the socialization of members into the community of practice, their transmission, and the likely transmission by students in the future.

In the following section, the need for physical experience and the role of tacit information are considered in more detail.

3.2 "Acidified is usually,- a few drops are enough" – tacit knowledge and corporeal information exemplified by acidification

The topic "What does acidification actually mean?" runs through the lab session in this study. Based on the discourse around acidification, core aspects of information practice can be highlighted, described as "getting a feel for phenomena" (Kirschner, 1992). The examples around the topic of acidification show how tacit and nuanced aspects of information practice need physical experience (corporeal information) and social guidance for a practical understanding. While physical or psychomotor struggles are included in lab activity research, they are often depicted in isolation, e.g., relating to issues with tools or non-functioning equipment (DeKorver & Towns, 2015; Keen & Sevian, 2022). What is missing in the research literature is the connection between the corporeal information modality and other information modalities that contribute to learning; this is important because the corporeal information modality is a necessity for practical understanding.

The results are illustrated in a model, Figure 3, which describes the students' development of tacit knowledge, referring to the concept of acidification for practice. Again, this model is not a representation of the complex information practice in this laboratory but a tool to display the central results concerning tacit information needs in this study.

In this study, both textual and social information modalities alone did not lead to a practical understanding of the group-specific concept of acidification for novices. The students needed the physical experience (corporeal information) in different scenarios, classified through social instruction by an experienced member of the community of practice to give practical meaning to the concept of acidification, the "interweaving of cognitive and physical sources" that gives meaning to the knowledge (Lloyd, 2010a). The dotted lines in the model depict the

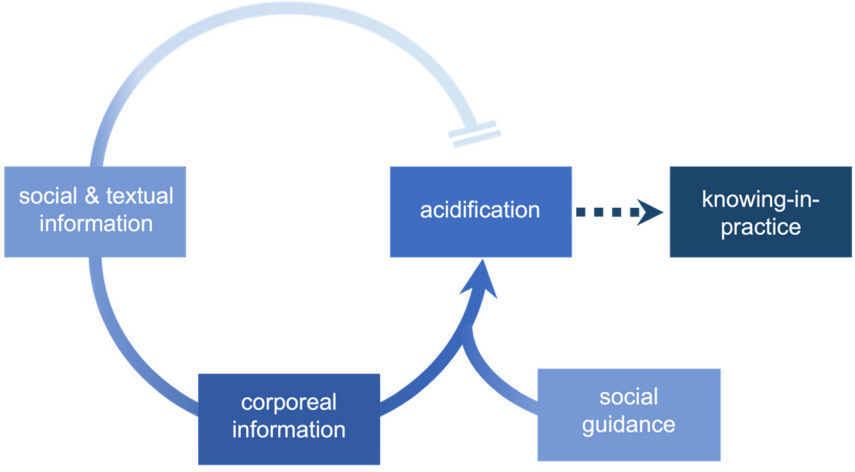

Figure 3: Illustration of students' information practice in the case of tacit information needs, exemplified by acidification.

necessity to repeat this process in different scenarios for the students to develop knowing-in-practice. The following section depicts how the model was derived from the data and discusses the results.

In the following example, students Johannes and Jakob begin by discussing the practical meaning of acidification:

> Johannes: "Now the question, what does acidifying mean? So how much should I add to it?"
>
> Jakob: "That's why I just wrote acidify and not somehow a specification because I have no idea. Ask the chemists somehow-. I think that's such a consensus among them that they all know what that means. And everybody else doesn't know. And that's why they always write acidified or acidifying."
>
> Johannes: "Yes, then I have to ask because I don't know either."
>
> Jakob: "Yes, I don't know either. Otherwise just measure the pH and add a little bit."

Jakob reflects that there is group-specific knowledge ("consensus") in the circle of "chemists" to which he has no access because he does not belong to it. He tells Johannes that if one belongs to that circle, then one knows it, and that there is no need to manifest that knowledge explicitly. During his research for the experimental procedure, he was not able to find anything explicit in writing on the subject of acidification. The textual information he found was not sufficient for him to make sense of the topic in practice.

Johannes does not know either about this topic, however, he shows no uncertainty about who he might ask. He has access to "chemists", i.e., access to the circle of those in the know (Johannes: "Yes, then I have to ask because I don't know either."). Jakob also suggests a further possibility for action, how information can be obtained alternatively – without asking anyone – or how they could act without additional information ("Otherwise just measure the pH and add a little bit."). This example documents the students' information need in the form of a social resource when textual information is insufficient.

In the following situation, Jakob asks Jana, the supervisor, about the procedure of acidification:

> Jana: "Well, in the lab practical it is very important that you simply try out a bit. There is no right or wrong here. Sure, you have your literature, you are well read, but-."
>
> Jakob: "Yes, but we are still a bit helpless, I think. What I've heard, in the literature, much is kind of already assumed. Basic things for chemists, for example: Acidify the solution. How much acid goes into it until it is acidified?"
>
> Jana: "Acidified is usually-, a few drops are enough. Then you look with the pH paper."
>
> Jakob: "Diluted by what, how much? Sometimes it says 2 mol, sometimes it says 5 mol. Then it says it in percent."
>
> Jana: "You usually take a hydrochloric acid, a diluted one. You add a few drops, check whether it's acidic or not, with the pH paper, and then it's usually ok. Otherwise, it will say strongly acidic or something like that."

Learning the ways of a community of practice takes place when people participate: "They learn not only about the actual performance of practice (e.g., the doing of practice), but they also engage with nuanced and tacit information (e.g., the saying of practice)" (Lloyd, 2010b). This excerpt shows how the newcomers to the practice question the "sayings of the practice." Jakob is frustrated by the unclear textual instructions and changing formulations. New members with a fresh look can challenge circumstances that the long-time community members take for granted. This example illustrates the difficult process of the students' experience with understanding "the saying of practice" and translating it into action.

The supervisor encourages the students to use "trial and error" methods independently of textual information. Nevertheless, they experience a need for information that they feel is fundamental to be able to act and, thus, they demand the information that is missing from the supervisor. They need access to the missing information through an experienced member of the chemistry laboratory practice who is privy to this kind of tacit knowledge, in this case, Jana. However, Jakob has previously suggested a possible course of action ("just add a little and measure the pH") which is also offered repeatedly by the supervisor during the discourse ("Acidified is

usually also-, a few drops are enough. Then you look with the pH paper"). Although Jakob has verbalized the same information as Jana, content-wise, he cannot act without further input, i.e., he cannot start experimenting in order to try something out. Although Jakob does not lack theoretical knowledge, he is still unable to take action.

Even though the content of the verbalized information on acidification is similar between the students and Jana, they have different practical experiences to give meaning to the information. The difference with these "basic things" is documented in the binary meaning of the word "basic": The term "basic" carries the connotation of being both fundamental and necessary for taking action, as well as the connotation of being primary or easy. For the students, on the one hand, the basics are fundamental prerequisites for action which is why Jakob reacts to the suggestion for trial and error with "We are helpless." They are at the beginning of their socialization in this community of practice. On the other hand, the supervisor's basics are self-evident and straightforward, however, she cannot elaborate on her instruction rooted in tacit knowledge. This can be seen in the example when Jana attempts to explain acidification: Jana: "Acidified is usually-, a few drops are enough." She cannot explicitly state what the concept of acidification is. Jakob responds with another request for her to clarify what acidification means, to make it explicit: Jakob: "Diluted by what, how much?" Jana, again, cannot clarify what acidification means, she can only explain how it "usually" goes and delimits acidified from "strongly acidic or something like that."

During the lab practical the supervisor draws on memories of situations she has experienced that she cannot express clearly and looks for procedures to verbalize to the students. These procedures are, for example, expressed by Jana when she attempts to explain acidification. She does not give a clear, explicit answer but she thinks about how "it is usually done." We interpret this as her drawing on her memory and how she "usually" experienced acidification. This can also be seen by her stating, "You usually take a hydrochloric acid, a diluted one. You add a few drops (…)," which clearly depends on the situation, but in her memory, this is how it usually happened. To explain a practical endeavor, she draws on her experience in practice.

The notion that Jana's understanding of acidification is rooted in tacit knowledge becomes clearer when she provides a definition of what acidification means in the next example, and then repeatedly contradicts it in the latter course of action. Johannes asks her what "acidify" practically means:

> Johannes: "Yes, I have another question."
>
> Jana: "Yes, sure."
>
> Johannes: "It says acidify. So I understand that I add an acid. But the question is how much. Because I can't estimate that now."
>
> Jana: "Yes. Acidifying means that it should be in the acidic range, yes. pH value below seven. And then you just add a few drops and then you can check with the pH paper whether it is acidic or not and test it first."

Jana clarifies that acidifying means "pH value below seven." The next examples will show that this, however, is not what she considers acidified in practice. During the discourse around the acidification of a solution, Jana suggested that Jakob should test the pH value of his sample first because it might already be acidic and not need further acidification, which he did. He negotiates the results with her in the following example:

> Jakob: "That is, I have about six to five now. So it's acidified."
>
> Jana: "Exactly. I would still-a little bit because that's really-, so that's not so clear. That's … even a little bit more-, yeah, it's still very neutral. I would add a little bit more."

Although the case that Jana proposed has occurred, she previously defined acidified – the solution is already in the acidic range – she is now dissatisfied with her previous definition of acidified. In her practical understanding, it is not acidified, "it's still very neutral." Jana has no explicit explanation for what acidified means, she just has a "feel" for the phenomenon (Kirschner, 1992). Ultimately, the students learn to acidify by experience and exclusion criteria, namely by practical examples classified by Jana as acidified or not acidified. The students attempt to acidify their samples by taking physical action and Jana classifies the experiences for the students.

This can also be seen when the contrary example occurs. The sample was supposed to be acidified but is now classified by Jana as "strongly acidic," which Jana points out to the students could be a disturbing factor for the test.

Jana: "Okay. Is there anything in it maybe? Because it is in the strongly acidic range."

Jakob: "What does strongly acidic mean?"

Jana: "Well, it said acidify."

Johannes: "Yes, I have-, pH value one I have."

When Jakob asks, "What does strongly acidic mean?" Jana answers with "Well, it said acidify," thus avoiding the question that requires an explicit answer. Again, the students learn about acidification by experience (corporeal information) that is classified by Jana (social guidance). She contradicts her former definition of "Acidifying means that it should be in the acidic range, yes. pH value below seven." What counts as acidified and what does not in practice clearly diverges from her theoretical explanation. There is "strongly acidic" and there is "too neutral," both of which occur in the range of pH < 7. Jana has passed her tacit knowledge on by categorizing the students' experiences. The students try "to acidify" and only then can she give them an estimation if they succeeded or not. To Jana, acidification is self-evident and intuitive. What is necessary for the students to learn about acidification is the physical experience of doing it, combined with the classification and guidance by Jana as an experienced member of the community of practice; the "entwining of cognitive and corporeal sources" that gives meaning to knowledge (Lloyd, 2010b).

These examples document how both the textual and social information modalities alone do not lead to a practical understanding of the group-specific concept of acidification for the beginner chemists (Ibid.). The students need the physical experience (corporeal information) classified through social guidance to give practical meaning to the concept of acidification. A common reference frame develops in a specific group through people engaging in practice together. Newcomers to a community of practice learn the sayings and doings of the practice and eventually become information-literate members who can act independently and decide situationally (Ibid.).

The acquired information, the sayings of practice, can have tacit aspects, as in the case of acidification, or clear and explicit aspects, as in the cases of disposal and safety. Both incidents require the physical experience of practice for the students to develop situational agency. However, in the case of acidification, the students need Jana to classify their findings in order to understand the concept of acidification for practice. In both cases, the students require experiencing multiple situations, which eventually leads to the shared conceptions between people belonging to the chemistry community of practice.

The following section will discuss ways to implement these insights into information practice for information literacy instruction.

4 Implications for teaching

Reconstructing aspects of the information practice in a beginner laboratory provides insights into students entering the laboratory practice as newcomers and the TAs guiding the students as experienced members. The results of this study have shed light on group-specific explicit and tacit aspects of chemistry laboratory practice and can be helpful for laboratory teaching and learning.

The results show that the TA plays a vital role in the students' learning experience in the laboratory, which aligns with findings from the literature (Good et al., 2015; Huffmyer & Lemus, 2019). The students unquestioningly accepted the social guidance provided by the TAs in this study. However, the results also show that many of the "doings of practice" instructed by the TAs sometimes lacked explanations altogether, or the reasoning was incomprehensible, for example, Jana advised the students against using gloves, explaining that "a little bit of acid" would not be too bad. A lack of an reasonable explanation can be problematic because the students might need

help understanding why the procedures and doings in the laboratory are performed in a certain way. The students' need for appropriate explanations concerning standard procedures is in line with existing literature on what students deemed one of the most important types of knowledge that TAs need: "knowledge specific to the laboratory experiment (procedures, techniques, and safety concerns.)" (Herrington & Nakhleh, 2003) However, a prerequisite for TAs to provide explanations is an awareness of these group-specific aspects of practice that, in this study, frequently appear self-evident to the actors. Clarifying the sayings and doings of practice in the beginner laboratory can be helpful for TAs to reflect on their practice and how they pass it on.

Even though the TAs in this study were experienced in the laboratory, they did not have previous laboratory teaching experience. New TAs are often eager to be perceived as capable of answering questions (Robinson, 2000), and, therefore, they might not clarify when unsure of the rationale for a procedure to maintain their authority. It could be helpful to include discourse excerpts from practice in TA training to create an awareness of potential difficulties in practice. For example, the acidification discourse excerpts from this study could be presented to the TAs with the question of how they would have dealt with it. In training, disposal and safety could be introduced as explicit group-specific aspects of information practice, and acidification could be introduced as an example of tacit aspects in the laboratory. Using these examples, TAs could reflect on their practice, how they learned things, and how and why they passed them on in a particular way. Further research is needed to uncover other group-specific aspects of information practices in the novice lab. TA training, including the "sayings and doings of practice," in order to ensure that they understand why they do what they do.

In addition to improving the explanations of doings in practice, the TAs could also check for the student's understanding. Huffmyer and Lemus (2019) suggest that TAs "should increase surveying for understanding to increase student achievement" (Huffmyer & Lemus, 2019). Aside from checking the student's understanding (Fisher et al., 2005) concerning subject content about the experiments, it could also be helpful also for the TAs to check for understanding concerning the group-specific doings of practice focused on in this study, especially in the beginner laboratory.

However, the idea is not to "transform" tacit information into explicit information or to generalize the rules of conduct. Nevertheless, reconstructing information practice shows how demanding this experience is for students. The difficulty of a beginner lab as a confusing and possibly overwhelming place is broadly discussed in the literature (Chopra et al., 2017; Kirschner et al., 2006). The students in a problem-based laboratory do not receive detailed instructions and are required to solve problems by looking for information largely independently. Similarly, the idea is to have TAs "respond with questions that help students make progress without making decisions for them." (Clark et al., 2016) However, having specific areas of direct instruction in problem-based laboratory teaching could be helpful to lighten the cognitive burden on the students (Kirschner et al., 2006). For example, the scenario around acidification that we discussed in this study could have taken the form of a demonstration by Jana, showing the students what she means by acidification. More research is necessary on how the chemistry community's group-specific knowledge is represented in practice and, thus, this article can only act as a starting point. With more thorough research, we could then determine more precisely when a situation can be understood as a "productive struggle" (Keen & Sevian, 2022). When we wish the students to engage in this struggle, or when we make it unnecessarily harder for them. Instead, we could aim to instruct them more clearly and remove some of the cognitive load and "general confusion" (Chopra et al., 2017).

Similarly, the findings of this study suggest that the students did not seek explanations for unclear information. For example, Jakob scrutinized the alternative modes of expression used in chemistry literature and was frustrated when the formulations changed between percent and mole. The importance of supporting students in critically evaluating textual information is discussed in the information literacy research literature (Li & Liu, 2022; Wellhöfer & Lühken, 2022a; Yevelson-Shorsher & Bronstein, 2018). However, no student questioned the information provided by their supervisor, regardless of whether an explanation was given or not. The study's excerpts demonstrate how internalized principles were passed on from teaching assistants to new members, increasing the risk that social information would be accepted without question. While current information literacy research focuses on improving the critical evaluation of written sources, the authors suggest a holistic approach. Students should be taught to understand that all textual information is fundamentally social and that they should apply a critical mindset to all information, including social sources.

One way to start this process is by teaching students to scrutinize all textual information as fundamentally social. A helpful example for this is forum information from the internet. The usage of Internet forum information for textual research is a popular way of gathering information for students because oftentimes, the information is easily accessible and easier to understand. This information can be used to exemplify and highlight its similarities to information acquired from peers (Wellhöfer & Lühken, 2022a). Ultimately, students should understand that the authority of sources is constructed and it is up to them to evaluate the required authority in a specific context (Association of College and Research Libraries, 2015).

From the students' perspective, their lack of awareness of the need for corporeal information and physical experience for their conceptual understanding could contribute to their insecurity. There are instances when the required information is not available in writing, and even when a supervisor is consulted, there may not be a precise answer as the required information may be rooted in tacit knowledge. The students may know that something is missing, but they cannot identify what it is. This is because the information must be enacted to become meaningful. Raising awareness of the necessity of physical experience for understanding could help students gain a better understanding of their learning process. One way to achieve this is by making this part of the learning experience transparent to the students. The Transparency in Learning and Teaching (TILT) approach (Winkelmes, 2014) encourages educators to discuss with students how and why they learn in a certain way. This approach could be applied to help students understand that laboratory practice requires physical experience for their knowledge to be meaningful in practice. By making these parts of learning more transparent to students, their feelings of insecurity in a beginner laboratory may be addressed.

This way, instruction includes the corporeal, social, and textual information modalities and how they are connected in practice. This understanding could lay the groundwork for the students to challenge and evaluate the "sayings and doings of practice". By acknowledging and incorporating the importance of physical experience and tacit knowledge, students can develop a more holistic understanding of their field of study, which can ultimately enhance their learning outcomes and reduce feelings of insecurity.

5 Limitations

This study refers to understanding information literacy through a practice theory lens. This approach understands information practice to be complex, contextual and fundamentally social. Thus, the aim is also to draw attention to the usefulness of practice theory for understanding and teaching information literacy and, ultimately, learning. The physical learning experience has so far been neglected in the educational and scientific discourse concerning chemical information literacy. However, this study can only provide the first indications of the usefulness of this approach; further studies are necessary to gain a broader picture of the information practice in the field. The main limitation of this study, however, is that it relies mostly on one group and, thus, needs further comparisons in terms of other groups of students. The study presents an in-depth qualitative analysis with no claim to generalization. The models we suggested are intended to help to understand the information practice in this study, referring to the different information modalities. However, they are limited in terms of their representation of the complex information practice in the laboratory also due to their sole reference to safety, disposal, and acidification. Nevertheless, further studies with regard to different scenarios in the laboratory are required to gain a broader picture of how social and physical experiences coin the information practice. Information literacy's contextual and social aspects are being increasingly acknowledged in educational research and practice. We believe that this work forms a good starting point and we hope that future research can emerge from this.

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