

# SCAFFOLDING STUDENTS' REFLECTIVE DIALOGUES IN THE CHEMISTRY LAB: CHALLENGING THE COOKBOOK

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*The paper reports on a cross-case analysis comparing students' activities and dialogue during BA level laboratory exercises, applying a mixed methods research design with video-data, student questionnaires and interviews. Our analysis identified specific affordances in relation to macro and micro-scaffolding of students' activities and dialogues, in order to stimulate them to work at higher cognitive levels. A lab-exercise in the course Macroscopic Physical Chemistry was redesigned with the aim of stimulating students' metacognition both before and during the experimental work. The redesign included a prelab task, related to planning experimental work and explaining theory, and a definite level of openness in relation to the choice of data points. The analysis of activities and dialogue during the laboratory work indicated that this rather simple redesign of a laboratory exercise successfully supported/stimulated student-student dialogue on course content. Furthermore, dialogue between students and teaching assistant revealed elements of exploratory talk including a dialogic approach with open questions and prompts. The students expressed that the preparatory assignments and the dialogue with the teaching assistant supported their understanding. The redesigned exercise cannot be labelled as a full inquiry-based laboratory exercise, but the students were scaffolded in guided inquiry, making definite choices related to calculations, representations, and assessing their data.*

**Keywords:** chemistry education, laboratory activities, scaffolding

## INTRODUCTION

Laboratory work is an established part of science education both at secondary level and in higher education (Reid & Shah, 2007). A range of challenges concerning student learning from laboratory activities have however been discussed in research. First of all, many laboratory activities are characterized by a lack of clearly defined purpose reflected in intended learning outcomes relating to both practical and generic skills, in addition to content understanding (Hofstein & Kind, 2012). Laboratory exercises are often instructed by the use of a cookbook-like manual, although it is well documented that this do not efficiently support students' learning of higher cognitive skills (Domin,1999). In contrast, decades of research have highlighted the potential of (guided) inquiry-oriented laboratory activities to engage students in higher order thinking via the manipulation of both equipment and ideas (Hofstein & Kind, 2012). Millar, Tiberghien and Le Maréchal (2006) for example suggest to raise the degree of openness, offering students more complete laboratory tasks including planning and designing experiments and getting feedback from peers and teacher.

Evidently, there appears to be a gap between research results and the actual development in the teaching laboratories i.e. at the universities. Educational development of the laboratory teaching might best be implemented in close collaboration with the scientific staff, identifying the intended learning outcomes and discussing how challenges evidenced also by local data

can be targeted. Such a process must include both the teaching assistants (TAs) who are often responsible for the main part of the direct instruction in the lab, and the professors who have more influence on the instructional design (Addy & Blanchard, 2010).

This paper presents data collected in the frames of an educational development process with teaching assistants (TAs) and professors at the chemistry department at our university. The paper does not report on the cooperative process per se, but on the evidence of students' activities and dialogues that was discussed in the process. These data inspired the collaborative redesign of a course, including specific initiatives to support students' pre-lab preparation and follow-up activities (Millar et al., 2006; Reid & Shah, 2007; Winberg & Berg, 2007).

## COMMUNICATION AND DIALOGUE IN THE LAB

Referring to a social constructivist theory of learning, dialogue among peers and with the teacher must be seen as essential for student learning outcomes in general, and in the laboratory in particular (Andersson & Enghag, 2017). Research has focused on how the teacher can support and scaffold student dialogue using a variation of communicative approaches (Scott, Mortimer, & Aguiar, 2006). A particular kind of student dialogue is the so-called exploratory talk where statements and suggestions are offered for joint consideration by the students, engaging critically and constructively with each other's ideas and sharing thoughts about phenomena (Mercer & Dawes, 2014). Exploratory talk is often hesitant and incomplete, but comprehensive research, mainly from the secondary level, strongly suggests the learning opportunities when students are trying out their conceptual understanding through exploratory talk (Barnes, 2009). Mercer & Dawes (2014) opposes exploratory talk to disputational talk, typically based on disagreement with assertions and counter assertions where students are not searching for developing a shared understanding, and cumulative talk when students build positively but uncritically on fellow students' ideas.

The teachers' scaffolding can be executed both at macro- and micro-level (Prediger & Pohler, 2015; Pollias, 2016). Macro-scaffolding refers to the planned sequencing of activities whereas micro-scaffolding refers to the immediate strategies the teacher uses in-class e.g. in dialogue, engaging students' perspectives and asking questions (Pollias, 2016, p. 98).

In relation to communication and dialogue specifically in the laboratory teaching at university level Andersson and Enghag (2017) have systematically analysed what students actually do and talk about during laboratory work in a university level physics course. They also among other theoretical references refer to exploratory talk, and call for more research looking into what is really going on during laboratory teaching at the university level.

This study provides such detailed evidence guided by the following research questions:

### Research questions

RQ1: What can be condensed as typical features concerning students' activities and dialogues during BA-chemistry laboratory exercises across courses at Aarhus University?

RQ2: What possibilities, challenges and specific affordances in relation to macro and micro-scaffolding students' activities and dialogues can be identified?

RQ3: What characterizes students' activities, dialogue and perceived outcomes working with the redesigned laboratory-exercise liquid-liquid phase diagram in the course Macroscopic Physical Chemistry?

## METHOD

A sequentially mixed methods research design was applied (Creswell, & Clark, 2007).

RQ1 is answered by analysing video-data, student questionnaires and interviews from three different local laboratory courses: General chemistry, Environmental chemistry and Ecophysiology. Possibilities and challenges have been identified by cross-case analyses (RQ2), and based on these findings some laboratory courses are now being redesigned, i.e. a lab-course in Macroscopic Physical Chemistry redesigned in close collaboration with the professor and TAs.

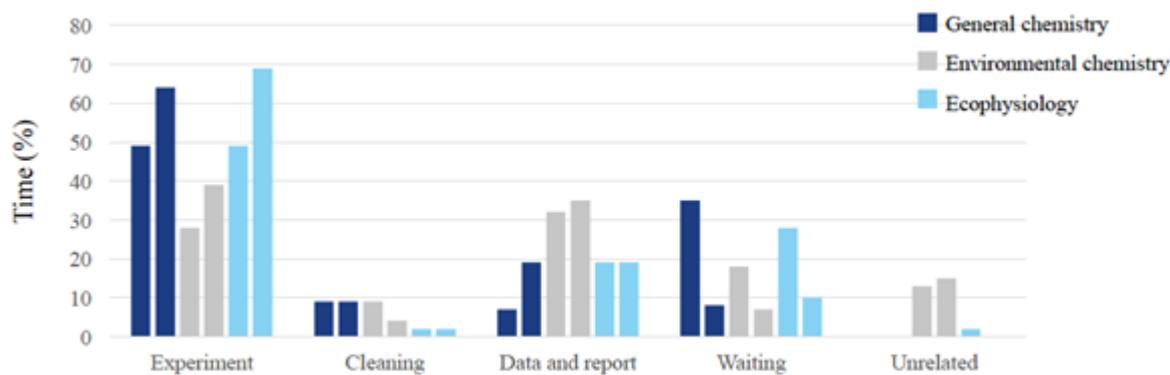
RQ3 is answered by a questionnaire (n=61) with both open and closed categories, administered to students after the redesigned laboratory exercise liquid-liquid phase diagram, video-data and post interviews from two groups of students, each with three students. The redesign of this specific exercise included both specifying and sharing the learning goals with students and letting the students construct a flowchart describing the experiment (pre-lab) and choosing data points, followed by feedback from the TA at the start of the lab. During laboratory exercises the students had to make a range of calculations, assessing and evaluating own results and assembling their data into a phase-diagram used as the basis for in-situ feedback and in a post-laboratory report. The questionnaire focused on the students' perception of the laboratory activities, and of their own preparation and learning process.

Interviews, video-data and open categories in the questionnaire have been analysed using data-based thematic analysis (Braun & Clarke, 2006). Open reflections from the questionnaire and video following two student groups in each laboratory exercise have been coded with the final categories, after an iterative process, and with a final quantitative coding with two coders, calculating inter-rater reliability. The closed categories in the questionnaire have been analysed by frequency and cross tabulations also including the coded open answers.

## RESULTS

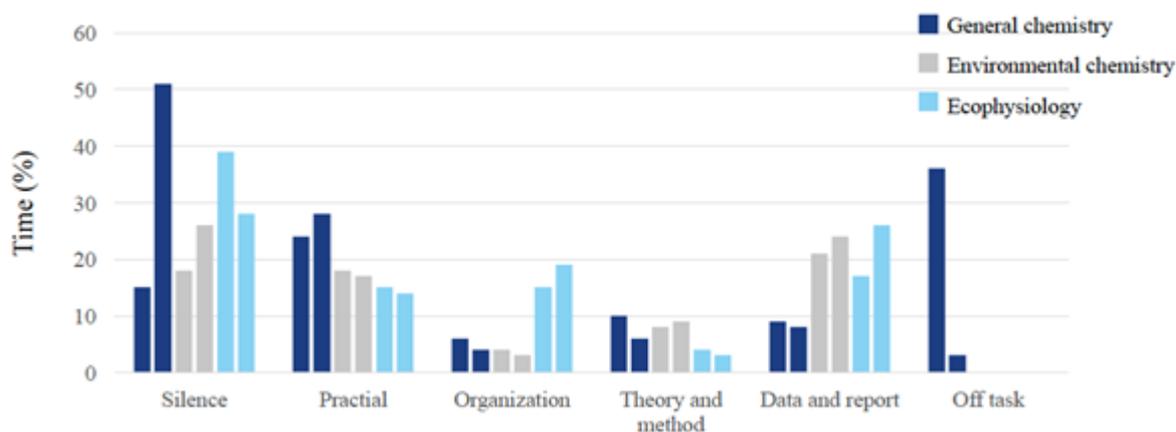
### Students' activities and dialogues analyzed in three laboratory courses

Cross-case video analysis of the three very different laboratory courses revealed rather large variations regarding how students spent their working time during (the same) laboratory exercise (Figure 1). Across courses it was however a general finding that relatively little time was spent talking about scientific concepts, theory and methods. The time spent in the laboratory for the groups of students in the three courses represented in Figure 1 varied between 2h 18 min and 5h 35 min, but the dialogue about science (theory and methods) was in all cases only 8-15 minutes (Figure 2).



**Figure 1.** Student activities during laboratory work quantified by coding video following two student groups from each of the three courses General chemistry (dark blue), Environmental chemistry (grey), and Ecophysiology (light blue). The data are represented as the percentage of the total amount of time the group spent in the laboratory.

Particular differences were identified on how students spent the waiting time, which is inherent to complex laboratory procedures (between 8% and 35% waiting time in the same laboratory exercise) (Figure 1). The analysis suggested that the teacher to a high degree affected students' behaviour during the waiting time. Thus, for the group with most waiting time in the General Chemistry course, it was observed that the TA suggested the group members to take a break spent with coffee, cake and small-talk during the waiting time. In contrast, the other group had much less waiting time because the TA suggested them to work on the data analysis, so in Figure 1 this is coded as "data and report".



**Figure 2.** Student dialogue during the laboratory work quantified by coding video following two groups from each of the three courses. The data is represented as percentages of the total amount of time the group spent in the laboratory.

The students themselves referred to the effect of the teacher scaffolding their work with the data immediately:

*"We usually just sit and watch. But the reason ... we worked on data/report.. was because [the TA] suggested we could spend our waiting-time on the report". (Interview)*

*"It has forced us to explore new ideas, which we would have postponed to the next day. There is no question about it". (Interview)*

It was as mentioned above a common finding across cases that only very little time, less than

10% of students' time in the laboratory, was spent on dialogue with peers or TAs about the theoretical content of the exercises and/or data and results (Figure 2). Dialogues between the students and the TAs during the laboratory exercises typically concerned how to use the equipment, but not how to understand the procedures or the theory. The dialogue was characterized by the TA using closed questions resulting in a predominance of interactive-authoritative or non-interactive communicative approaches (Scott et al., 2006).

Many students expressed that they just followed the cookbook and postponed further understanding:

*“I only focused on collecting the data ... that is primarily how exercises works for me. It has something to do with collecting data and then there's the theory – that somehow comes afterwards”.* (Interview)

When asked about their use of content specific knowledge during the laboratory work, between 12% and 50% of the students stated that they used their content specific knowledge. This suggest that the majority of the students complete the laboratory work without having talked or thought about the theory related to the experiment. This is reflected in the following student quotes from the interviews:

*“..just do what you are told and take the numbers and put them into the given formula and then you get the precise results you are expected to get..”*,

*“..it is more about answering than understanding..”*.

Summarizing the data from the cross-case analysis it is clear, that the students perceive their work in the laboratory as unconnected with the theory. The students both in survey and interviews expressed that they applied their scientific knowledge only to a very limited extent during their time in the laboratory. This was not explicitly problematized by the students, suggesting that they might be enculturated into an instructional approach where they are expected to follow a cook-book like recipe step-by-step.

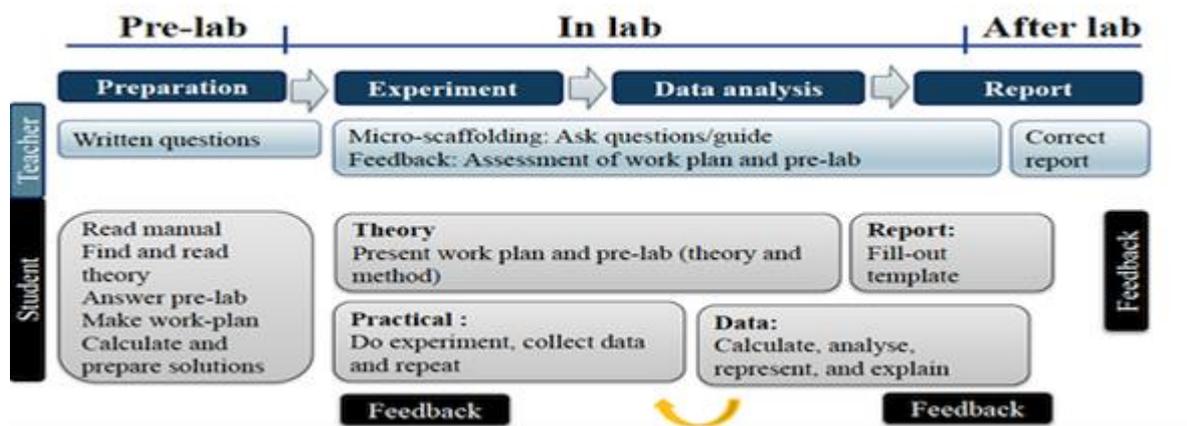
This “doing without understanding” was however problematized when discussing the local data with scientific staff. Based on these discussions in the educational development process, a new laboratory exercise in the course “Microscopic physical chemistry” was developed with the purpose of stimulating students' scientific thinking and subject specific dialogue.

### **The redesigned lab-exercise liquid-liquid phase diagram**

The redesigned laboratory exercise is related to the concept of Phase Separation and involves the constructions of a liquid-liquid phase diagram based on students' own measurements. The various elements in the redesign of the laboratory exercise liquid-liquid phase diagram are illustrated in Figure 3. The model used in Figure 3 to represent the redesigned course is presented and discussed in more generic terms in the perspectives below. This model was introduced as a tool in the educational development process.

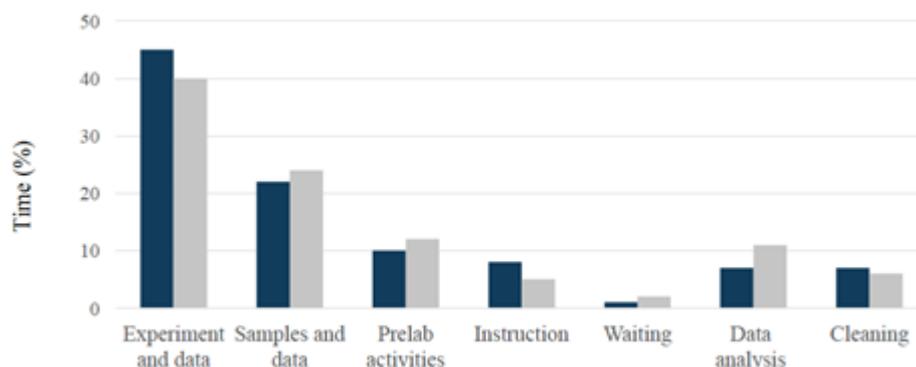
The most prominent feature in the instructional design (Figure 3) is that students are provided with a laboratory manual, which contains only minimal information about the theory related to the experiment. Instead, students are guided towards acquiring and applying the relevant theory

by conceptual questions and experimental predictions to be answered before the laboratory class (pre-lab). In addition, it was required that the students completed a work-plan describing in details how they would carry out the experiment. This part contained a certain degree of openness (Millar et al., 2006), since the students should decide on their own which dilutions to make, and which points of measurements to take. Based on their initial measurements they were asked to repeat the experiment and adjust the conditions to obtain a better diagram (represented by a yellow arrow in Figure 3).



**Figure 3.** The instructional design in the redesigned course in physical chemistry. The model describes the teacher (blue) and student (black) tasks *before* the laboratory work (pre-lab), *in the laboratory*, and *after* the laboratory work. The yellow arrow represents a step where students are expected to adjust and repeat their measurements based on their first set of data.

Analyses of the video observations from the redesigned exercise showed no significant differences between time spent on the overall activities when comparing groups (Figure 4). This is opposite to the cross-case analysis above, where significant differences in the macro-structure of the work in the student groups were observed within the same course.



**Figure 4.** Students' activities during the laboratory work in the redesigned experiment liquid-liquid phase diagram. Activities were quantified by coding video following two student groups. Each series represents one group. The data are represented as the percentage of the total amount of time the group spent in the laboratory.

In general, the observed students spent quite a lot of time talking about chemistry-related topics with each other and the TA. In average 33 % of the conversations during their time in the laboratory were related to higher order cognitive tasks, such as understanding chemistry theory and evaluation of data, and 50 % were related to more practical issues related to the experimental work. Several indications suggest that the macro-scaffolding of students' pre-

laboratory work established the base for the qualified scientific dialogue. As one student expressed:

*“The pre-lab questions are really good... then you know what you are doing as you go along. In other modules, you often just follow the manual and then afterwards you figure out what you did”.*

In the interviews, the students expressed that they appreciated this type of instructional design, and that it affected their motivation and learning during the laboratory work, here exemplified with quotes from four students from the interviews:

*“It is a useful way to do a report with these questions ... at least it's a more fun way to do it”*

*“Yes, I also think you learn more, better.”*

*“I think this works better than just going for it and not think about anything until afterwards...”*

*“Yeah, then you'll have an idea about what to expect from the experiment.”*

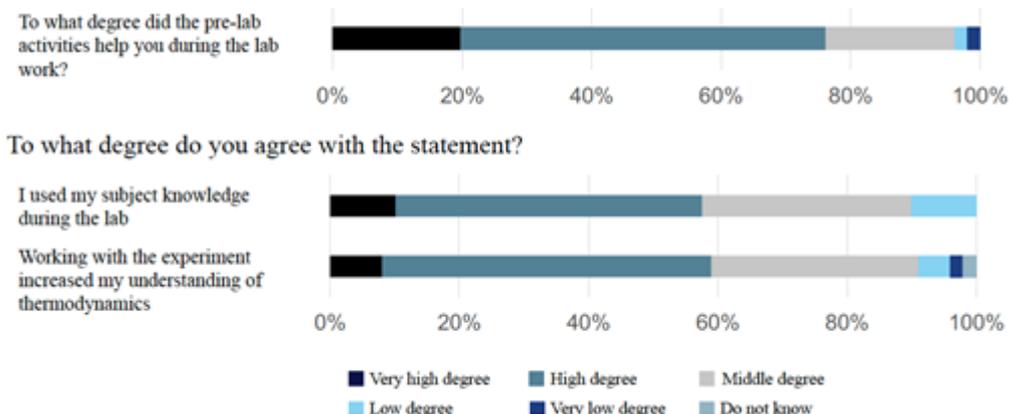
It was also clear that the micro-scaffolding from the TA, posing open questions and providing prompts, was of significant importance for initiation of dialogue about chemical theory. Dialogue about theory and method was 34-52% of the student-TA dialogue versus 20-27% of the student-student dialogue.

A detailed analysis of the dialogue demonstrated that the majority of the student-TA dialogue was interactive-dialogic (Scott et al., 2006), and 20% could be classified as exploratory talk (Barnes, 2009). Several students in their open reflections specifically mentioned that the dialogue with the TA supported their learning:

*“..the TA added new knowledge by asking questions and explaining”.*

*“Sometimes you'll just stand there feeling uncomfortable having to decide something and know the answer beforehand. This time the TA helped us and that was really nice”.*

In the questionnaire, nearly 80 % of the students stated that they found the pre-lab activities helpful to a “very high degree” or to a “high degree” (Figure 5). They also reported about using their subject knowledge during the laboratory work to a considerable higher degree than seen in the cross-case analysis.



**Figure 5.** Students' application and learning of thermodynamics in the laboratory. A graphical representation of students' answers related to the application and learning of thermodynamics in the laboratory (n= 58).

## DISCUSSION AND CONCLUSIONS

It is evident that the students who attended the redesigned laboratory exercise “Liquid-liquid phase diagram,” spent more time on dialogue about the experiment with indications of higher order thinking, compared to the typical pattern seen across cases. The students’ pre-lab work with theory and planning of laboratory work and their work on plotting and adjusting a phase-diagram based on own data, can be seen as a macro-scaffolding structure (Pollias, 2016). This supported the students’ metacognition: planning how to approach the learning task, monitoring comprehension and evaluating progress (Hofstein & Kind, 2012, p.198). Furthermore, the macro-scaffolding helped to avoid the great differences in the macro-structure across student groups seen in the cross-case analysis. In our interpretation, these differences in how the time was spent in the laboratory in the same exercise could be due to some of the students “doing without understanding”. This is supported by the students’ utterances in the interviews (quotes above).

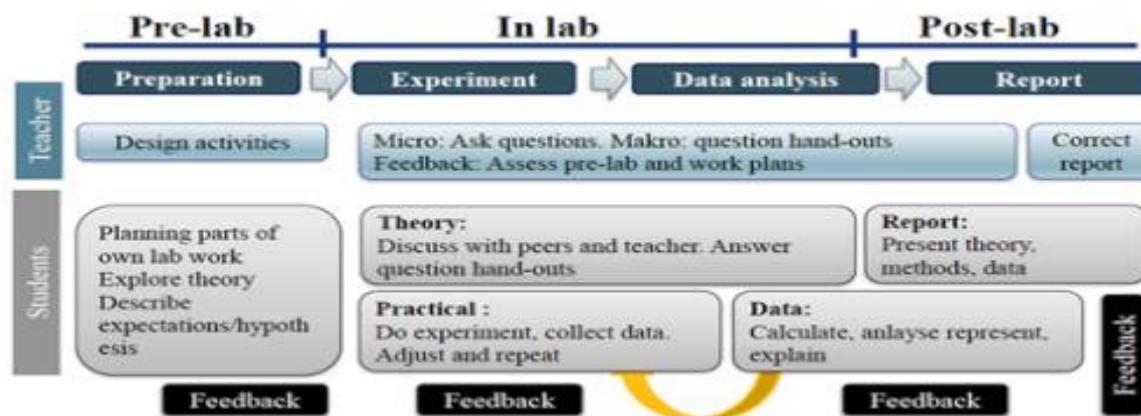
Opposite to this there were of course differences between groups at the micro-level also in the redesigned course, for example in the dialogue. This is mirroring the micro-scaffolding (Pollias, 2016), where the TA successfully targeted the challenges experienced by the individual student groups on the spot. Examples of dialogues between the students and the TA revealed elements of micro-scaffolding their exploratory talk (Barnes, 2009) by using open questions and prompts, and a more dialogic approach (Scott et al, 2006) than the average approach seen in the cross-case analysis.

In the questionnaire, the students expressed that talking with the TA influenced their learning. Furthermore, they expressed that the pre-lab work, supported their understanding during the laboratory work.

Concluding on this research it seems that a rather simple redesign of a lab exercise can successfully challenge the typical cookbook approach. The redesigned exercise cannot be labelled as a full inquiry-based lab exercise (Hofstein & Kind, 2012), but the students were scaffolded in guided inquiry, working at higher cognitive levels (Domin, 1999), making their own calculations, representations, and assessment of data both pre- and during lab.

## PERSPECTIVES

The findings presented have implications both for laboratory teaching – how to support student learning in the laboratory – and for educational development at the university. The findings confirm what have been seen in several studies internationally, that a cookbook approach is still frequently used in lab courses at university despite years of research advocating inquiry and context based approaches (Hofstein & Kind, 2012; Reid & Shah, 2007). The good news is that a rather “simple”, but focused redesign thoroughly planned in collaboration between educational developer and academic staff from the science department seem to have rather large effects on some of the challenges identified in research in relation to this predominant cook book approach. So, such small steps with degrees of openness (Millar et al., 2006) planned collaboratively might be the way to work on the gap between what is recommended based on research and the actual practice in the laboratory teaching at many universities.



**Figure 6.** A generic version of the model used in the educational development.

The model represented in a generic version in Figure 6 was used above in Figure 3 to illustrate the concrete instructional design. The model describes the teacher (blue) and student (grey) tasks before the laboratory work (pre-lab), in the laboratory, and after the laboratory work. The yellow arrow represents a step where students adjust and repeat their measurements based on their first set of data and formative feedback. Looking forward, we are using the model in the continuing work on educational development i.e. in redesigning laboratory courses at our university.

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