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Student guides: supporting learning from laboratory experiments through across-course collaboration

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ABSTRACT: We have observed that students often struggle with laboratory experiments. There is a high threshold to getting involved hands-on for fear of ruining an experiment, losing time, or breaking the equipment. More importantly, students have difficulty connecting the theory they learn in lectures and exercises with observations they make in the laboratory. As a result, it is challenging to formulate hypotheses, figure out what observations are needed, and make and interpret observations. We address this challenge by creating across-course collaboration between a basic- and an advanced-level *Ocean and Atmosphere Dynamics* course, which run during the same study periods and are typically taken in subsequent years.

We train students from the advanced-level course to act as "guides" and to support groups of basic-level students doing laboratory experiments with the practicalities of running the experiments, making observations, and facilitating discussions about interpretations by asking open-ended questions. This benefits students from both levels: Basic-level students appreciate the help with new lab equipment and the supporting questions that help them make sense of observations. Advanced-level students understand the importance of questions in the learning process and realize how far they have come in understanding the topic in just one year. They report they would like to act as a guide again.

We reflect on which design criteria help make this across-course collaboration successful and where we still see room for improvement. Based on our experience and evaluation, we present recommendations for other teachers that might want to try a similar approach.

1 INTRODUCTION

Students often experience difficulties applying theoretically taught concepts to the real world. Therefore, opportunities for practical experiences are often implemented in STEM teaching, e.g., by including laboratory classes in the curriculum. They can be used to explore new concepts before they are taught theoretically or to confirm a theory that has been previously studied (Chen et al., 2016). We aim to create scaffolded hands-on learning situations (Wood et al., 1976) that fall into students' zones of proximal development (Vygotsky, 1978). The learning situations should be at a level of difficulty that is challenging but possible, where students make sense of new concepts, especially when supported by others.

We involve students as much as possible in shaping their learning (Cook-Sather et al., 2014; Bovill, 2020) to create conditions that enhance intrinsic motivation, such as experiencing competence, autonomy, and relatedness (Deci and Ryan, 2000). We strive to create a Community of Practice (CoP, Wenger, 1998; Wenger et al., 2002) where teachers and students learn together and from each other. In a CoP, there are different legitimate roles regarding area and level of experience and expertise, goals, and responsibilities. Specifically, being on an "incoming trajectory," i.e., being new and on a steep learning curve, is a valued and legitimate role. Supporting students' learning through support from more advanced students is common (Crowe et al., 2014; Wheeler et al., 2017), but the more advanced students also learn from teaching (French & Russel, 2002). Bringing students from different stages of a study program together let students experience that it is normal and accepted not to know something and that subsequent attempts at shared sensemaking (Odden and Russ, 2019) can be a joyful and rewarding experience.

This article focuses on how we can enhance learning related to practical tasks through collaborations between students at different stages of their education. In shared laboratory sessions, we engage a whole course of advanced-level students as "guides" for basic-level students. We – three teachers and one student – present a case study of student and teacher perceptions of the benefits and challenges of such across-course collaborations.

2 THE CASE STUDY

Our study takes place at the Geophysical Institute, University of Bergen, Norway. In our case, attendance at course sessions is encouraged but not compulsory, with the exception of few, selected sessions that are part of the assessment. We educate students in atmospheric, ocean, and climate science. Students often find the physical processes related to large-scale fluid dynamics, such as the effects of Earth's rotation, challenging to imagine and understand. Therefore, we developed a new laboratory session in our introductory course, "***Physics** of the Atmosphere and Ocean*" (GEOF105), which runs in the fall semester. In this laboratory session, we use rotating table setups based on Hill et al. (2018) to give students hands-on practical experience with rotation and be able to describe the characteristics of a system in rotation compared with a system at rest.

In the fall semester, we also teach a more advanced fluid dynamics course, "***Dynamics** of the Atmosphere and Ocean*" (GEOF213). The students in GEOF213 are more experienced with theory and practical experiments, typically taking it a year after they took GEOF105. Before we started the across-course collaboration between these courses we made a pilot test in 2020, where we paid three volunteer advanced-level students from GEOF213 to act as teaching assistants. Although we expected both assistants and students to benefit from the collaboration, we focused mostly on the students' experience. However, the hired assistants were very positive and made it clear that they strongly benefited from the collaboration. It was exciting to hear them reflect on their own learning and appreciation of the session. Based on their feedback, we decided to make these benefits available to all advanced-level students from GEOF213, instead of hiring select students. We designed and formalised the across-course collaboration for one laboratory session. The laboratory session is compulsory for the basic-level students as the laboratory report is part of the course's assessment. It is voluntary for the advanced-level students to participate, and we experience that most students choose to participate when we encourage them and promote the learning opportunity. The collaboration is integrated in their course as a valuable learning experience, letting them revisit the previous year's content that they are directly building on in GEOF213. The two-hour collaboration takes place during a time that works with all students' study schedules. We have run the session since 2021, and here, we report on the evaluation from the latest iteration, autumn 2022.

In 2022, the GEOF105 cohort comprised 29 students from two different study programs (the 3rd semester of the "*Bachelor's Programme in Climate, Atmosphere, and Ocean Physics*" and the 5th semester of the *"Energy Integrated Master's"*). The cohort from GEOF213 comprised 13 students from both BSc and MSc study programs (the 5th semester of the "*Bachelor's Programme in Climate, Atmosphere, and Ocean Physics* " and the 1st semester of the "*Master Programme in Meteorology and Oceanography"*). GEOF105 is taught in Norwegian, while GEOF213 is taught in English. Eight students from GEOF213 had previously followed the GEOF105 course, including the lab session. The remaining students from GEOF213 were a mix of international exchange students (4 students) and one Norwegian student with a bachelor's degree from another university. We consider the student groups from GEOF105 and GEOF213 as the basic-level and advanced-level students, respectively, and want to stress that we think all of them are learners in the lab sessions. Still, for simplicity, we refer to them as "students" and "guides" in the following, to emphasize that we do not label the advanced-level students as teaching assistants to stress their role in the collaboration.

Before the joint laboratory session, we train the guides. First, they run the experiments and discuss different aspects of the observations and the accompanying theory. Second, they co-create a list of questions they think are relevant and discuss how to best support the students in making observations and discussing the results. We emphasize that it is important not to answer all questions immediately but to facilitate the students' discussions by providing hints or asking new questions that help them find the answer themselves.

During the joint laboratory session, we pair groups of three students with one or two guides. Each group has its own set of equipment and runs the experiments in parallel with the other groups. The laboratory experiments are structured and scaffolded through a lab guide, handed out on paper, that contains instructions, discussion prompts, and space for students to take notes and draw. The teacher is also available to support both students and guides.

To evaluate this new form of across-course collaboration, we employed several different instruments:

- We used pen-on-paper questionnaires with questions on a 3-point scale ("fully agree," "partly agree," "disagree") as well as some open questions to survey the students' and the guides' perceptions of the experience.
- The students' laboratory reports contained a section with free-text meta-reflections.
- The experienced teacher of the course and a student guide provided us with expert observations.

3 RESULTS

We report on student and teacher perceptions of this case study, first for the students, then for the guides, and the teachers.

3.1 Students

Students are generally satisfied with the experience of the lab session and their learning. All students agree (90% fully agree, 10% partly agree) that the experiments helped them visualize a theoretical or abstract term (Fig. 1a). They also reported gaining a deeper understanding of the phenomenon and agree that the experiments increased their interest in scientific processes and motivation for further studies.

The guides helped the students feel safe handling the equipment and securing necessary observations (Fig. 1b, c). In most student reflection notes, students describe their appreciation of the guides and how the guides helped them make better observations during the experiments. We provide a few quotes here as examples (translated from Norwegian):

> *"It was reassuring to have a guide who knew the experiment so that we were sure that we did not make any mistakes…."*

> *"It worked great with a guide. Since we did not know what would happen, it was useful to have a guide that could pay attention to what we were looking at and point us in the right direction when we missed out on any observations. In previous courses, we typically had a few laboratory assistants covering the whole class. That increased the threshold for getting help compared with having a guide available during the whole session."*

> *"Having a guide from GEOF213 did help a lot in knowing what to look for during the experiment, which was helpful to get as much as possible from doing the experiment. Without the guide, it would have been easier to miss key points during the experiment."*

The guides also facilitated the discussions by asking questions that made the students reflect on different aspects of the experiments. The students largely agree that the guides were helpful with this aspect (Fig. 1d, e, f). For example, two students describe it as follows:

> *"[The guide] asked good questions to help us see the connection between the observations and processes in the ocean and atmosphere. He made us discuss and try to understand more about why the [food dye] moved as it did."*

> "[Asking questions] helped the group to discuss with each other, and it was especially helpful when the conversation stopped."

Some students found it frustrating that the guides were not answering their questions directly:

> *"The only frustrating thing was that the guide would not answer questions on what happened [in the experiment]."*

However, students also reflected on the guides' roles and how they could prepare more to ask better or more helpful questions:

> *"I know that the guides were instructed to ask questions, to help us think ourselves and point to essential features, but asking good guiding questions wasn't easy. It would have been better if the guides prepared more before the experiment."*

The students report being reluctant to take on the role as a guide the following year when they would take the advanced-level class (Fig. 1h). Only 28% of the students fully agreed, and equal amounts (35%) partly agreed or disagreed that they would like to take on the role as a guide.

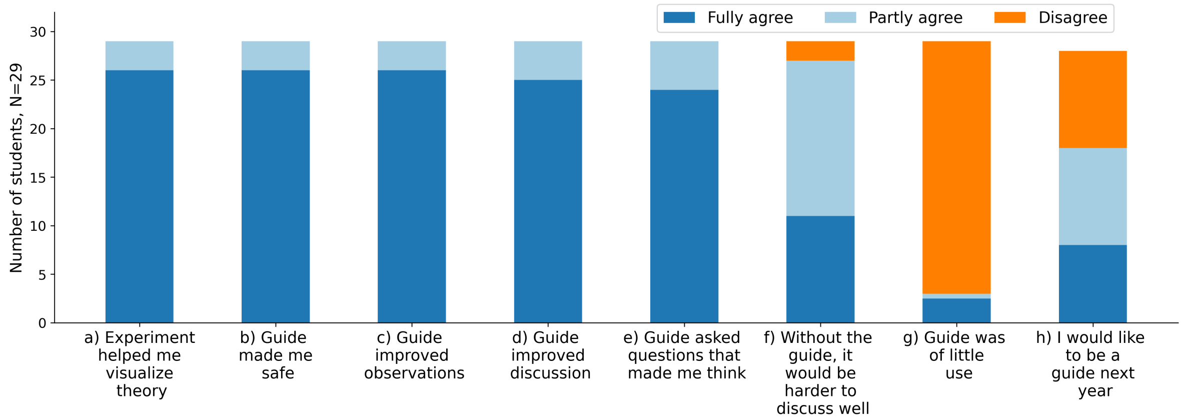

Figure 1. Students' survey responses concerning their learning and the role and value of the guides. The colors indicate the level of agreement with the quotes a-h).

3.2 Guides

Most guides reported that they learned new aspects of the experiment and became aware of their own learning during the past year through their role as guides (Fig. 2a, b). Co-author A.D.Å. describes her experience as a guide after having been a student the previous year:

> *" I was surprised at how different my experience of the lab experiment was as a guide compared to my experience as a student. It was very satisfying to come back a year later and feel so much more confident about the lab because I could see how far I had come since GEOF105. The theory behind the experiment was clearer the second time as a guide. It was generally nice to feel a sense of achievement in my studies. We as students learn new theory every week, so we usually focus on everything we don't know instead of seeing how much we have learned."*

Most guides also reported no discomfort in their role during the lab experiments and would be happy to act as a guide again (Fig. 2c, h). In addition, several guides reported that they enjoyed the session and thought it was fun. One guide commented, *"It is a great opportunity to learn together."*

Many guides were impressed by the students' level of knowledge and reported that the students could handle the discussion well without their help (Fig. 2g). However, most guides reported that the students benefitted from help to make good observations and being assured of what to do (Fig. d, e). From the guides' free-text answers, we received quotes such as:

> *"It was a competent group [of students] with much independent discussion and good questions and observations. It was fun and I learned a lot."*

Some guides reported that it was hard to know what to say and what not to say and also to find the best moment for asking the different questions:

> *"It is hard to give hints without giving the answer."*

> *"It is important to find the right timing to ask guiding questions. When they feel confused about the steps/outcomes of the experiment."*

However, the guides also understand that students should think themselves and enjoys that students engage in good discussions:

> *"It was tempting to answer, but important to let the students think themselves."*

> *"It was frustrating to not be able to give direct answers, but very fun when the students arrived at the answers themselves."*

A few guides report being stressed by difficult questions from the students. This indicates that we could improve the student guide training and preparation for the task. The language was also pointed out as a barrier for those who did not speak Norwegian.

In contrast to many of students reporting that they would not like to be a guide themselves (Figure 1h), all student guides reported that they would like to be a guide again (Figure 2h).

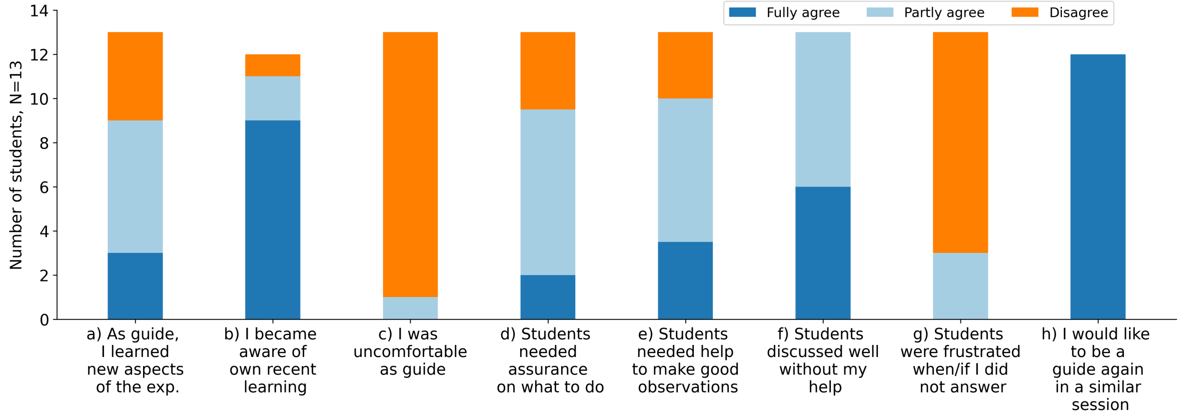

Figure2. Guides' survey responses concerning their learning and their role as guides. The colors indicate the level of agreement with the quotes a-h).

3.3 Teacher observation

We, the teachers, have observed a change in the laboratory session with the introduction of across-course collaboration. Firstly, from our observation and interpretation, the session has become more enjoyable for both teachers and students. The students appear to be less worried. They consult their student guides instead of waiting for confirmation or input from the teacher to proceed with their work. This also frees up the teacher's time to pay extra attention to groups that struggle and helps ensure that all students participate and learn from the activity.

In addition to freeing up the teacher's time, the guides ensure better use of the allotted time. Most groups finish before schedule, leaving extra time for other activities. Some groups use the extra time to vary the task and experiment with the setup, while others spend the time discussing different aspects of the course and study program with the guides (e.g., upcoming fieldwork or exam preparations).

In addition to helping students with practical parts of the experiment, the guides appear to improve the students learning. Firstly, the experiments have generally been more successful after introducing the guides: The students make better observations and fewer mistakes, making it easier to write their laboratory reports. Secondly, we notice that the guides improve the quality of the discussion during the lab session, which helps the students write better laboratory reports: We observe more focused discussions, and more students can connect the experiment to real-world processes.

4 DISCUSSION

A laboratory session can be chaotic, especially when only a handful of teachers and assistants can help the students. Assigning a guide to each group completely changed the atmosphere in the room. Most groups worked efficiently with support from the guides. They followed the laboratory instructions and consulted the guides when they had questions or doubts. They did not need to wait for teacher input to proceed with their experiments.

The guides' roles are to oversee that the students do the experiments according to the instructions, make relevant observations, and facilitate the students' discussion of their results. At the start of the session, we convey this message to ensure that both students and guides know their roles. Both students and guides reported that the guides' assurance of the procedure was helpful (Fig. 1b, 2d) and that the guides ensured that the students made good observations (Fig. 1c, 2e). The students also appeared more confident in running the experiments compared to previous iterations of the session.

The students were comfortable asking questions and understood that the guides were not there to provide all the answers. However, some students reported it was confusing and difficult to find the right answer. This is however not negative, this is just how learning works. Some guides also reported that it was hard to handle all questions. Some questions were difficult, and it was tempting to provide answers instead of hints and new questions. However, several guides reported that seeing the students arrive at the correct answers was fun. The dynamic between students and guides varied from group to group, and some guides and students were less confident to participate in the discussions. Perhaps some guides – and then the groups they guided – would have benefitted from more thorough training and preparations of questions and answers. To equal the levels of the groups, we could also run an evaluation session after the laboratory session, where we mix the groups and have them discuss their experiences, observations, and ideas about the theory. Many students are not used to doing experiments before learning the theory and do not know how to deal with the unknown. In the evaluation session, the teacher could ensure the students get access to the same information and theory explanations. Also, if any groups get dubious results, they can discuss them with others and determine if they did something wrong or if all groups arrived at the same result.

Most students fully agree that the guides improved their discussions (Fig. 1f). In contrast, the guides report that the students discussed well without their help (Fig. 2f). This could mean that the students felt overwhelmed by the experiments and did not notice how much they know already, or how they argue and discuss the results. The guides, on the other hand, have more experience. They see the valid points the students are making, and perhaps, they remember being in the student's shoes a year earlier and feeling like they know very little.

The quality of the students' lab reports improved after introducing the across-course collaboration, and we infer that the guides positively affected student learning. The students were more confident in describing the experiments and discussing the results, indicating that they learned from the discussions with their peers and guides in the laboratory classroom. Vygotsky describes the zone of proximal development as "*the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers*" (Vygotsky, 1978). In this laboratory session, the guides acted as more capable peers who contributed to better discussions and supported the students' sensemaking and learning. The guides ensured that the students understood key points before proceeding with the next step of the experiment. They ensured the students wrote down their hypotheses and encouraged them to discuss and describe their results.

Co-author A.D.Å's experience as a student guide agrees well with the observations from the teachers. She summarizes her experience as follows: My experience from being a guide in this study is that it improved the quality of the experiment and the discussion among the students. I believe it was beneficial for the students to have someone with them for two main reasons. Firstly, it was helpful to have someone to explain the setup and instructions that were given. My group of students was unsure about the instructions, and I think they would have focused too much on whether they were doing everything right instead of paying attention to the experiment and making important observations. This also made the experiment more efficient, leaving extra time to make observations and discuss. Secondly, it was helpful for the students that I could hint at what they should be looking at and ask them open-ended questions to guide their discussion.

A.D.Å. also observed that the students were a bit hesitant in expressing their thoughts when discussing what they observed in the experiment. This could be because they had a guide present who knew the "right answers," which may have made them afraid of saying something wrong. Although the threshold for students to ask questions is often lower when asking someone who is also a student compared to asking a teacher (Vygotsky, 1978), they still hesitate. The hesitation could also have been because the students were doing an experiment based on a theory they had not learned in advance, or it could be the dynamic of the group. A.D.Å. experienced that the discussion would often stop because of this, but open-ended questions helped the students continue the discussion and realize important points about the experiment. All in all, A.D.Å. observed that it was helpful for the students in her group to have a guide there to answer questions about the setup and the instructions and to have someone to guide the discussion with open-ended questions.

The only negative feedback we received was from students in the first (out of two) laboratory sessions, who had two guides who did not speak Norwegian. We observed collaboration challenges in this group, with little communication between students and guides. There could be several reasons why the collaboration did not work for this group. Firstly, both students and guides reported that the language was an issue. The students in this group were not comfortable discussing in English, but the guides did not speak Norwegian. Secondly, the guides were international students who had not done the basic-level course, and they did the experiments for the first time during the guide training and preparation. Third, there could be cultural issues or issues related to personal characteristics among students and guides. After observing how this group's collaboration turned out, we made changes for the second laboratory session. Here, we asked the students to volunteer to have an English-speaking guide. The students who volunteered were confident in speaking English, and the collaboration worked well.

Interestingly, the guides were comfortable in their roles and would happily serve as a guide again (Fig. 2c, e). At the same time, many students reported that they would not like to be a guide (Fig. 1h). We speculate if the students are reluctant to act as a guide because they feel uncertain about the theory. On the other hand, the guides said (personal communication) that they had learned so much theory and gained much more practical experience since they did the basic-level course that they felt confident and competent to guide. They also learned new aspects of the theory while preparing to guide and realized how much they had learned recently (Fig. 2a, b), which made the whole task more interesting and rewarding. Perhaps a shared evaluation session between the teacher, students, and guides would have been good to implement. Then the students and guides could share their perceptions of how the collaboration benefited them, and we can co-create further improvements.

When the students had completed their tasks before the end of the session, we overheard several students-and-guide groups discussing other aspects of the experiment or guides sharing experiences from their studies. Both students and guides agreed (92% of guides and 96% of students) that the joint lab experiment offered a good opportunity to get to know students across cohorts.

5 RECOMMENDATIONS

Based on our experience with the across-course laboratory collaboration, we compile recommendations for designing a similar learning activity in other courses. Across-course collaboration is scalable to larger courses, however, the ratio of advanced-level guides to basic-level students per group should be considered carefully to ensure participation and learning for both student groups. The two courses should also, ideally, build on each other so that the advanced level students get the benefit of seeing their own learning and development within the field.

5.1 Before the collaboration

Since this is likely the first time students experience such collaboration across courses, it is very important to prepare both students and guides adequately for their respective roles (e.g., explaining expectations for guides to ask questions and not answer student questions directly) and explaining the benefit for both students and guides (e.g., that even though they are working on the same materials, the intended learning outcomes are different, and achieved through their different roles).

Guides need the chance to get to know the materials the students will work with later so they don't read them for the first time at the same time. Guides also benefit from discussing their role with each other and collecting "good questions," so they feel competent to handle and facilitate the students' discussions, especially since the order of learning activities starts with a concrete experience and reflection of it before diving into theory, is opposite to what students are used to.

5.2 During the collaboration

We found it helpful to remind everybody of the expectations of the students vs. guides, i.e., be very explicit again that guides are not there to provide answers but to help students develop them themselves. Repeating this in front of everyone helps guides stick to this new and challenging role.

Since the benefits of discussions across courses extend beyond the specific intended learning outcomes, make sure there is sufficient time allocated so the students and guides can also talk about other relevant topics (e.g., upcoming elements of the study program or social events). This can help build across-cohort relationships and serve an important function in terms of information flow.

Even though you probably trained highly effective guides, be available as a teacher and prepare to support both guides and students (the session is not something that runs all by itself).

5.3 After the collaboration

One important benefit of the collaboration, for both students and guides, is the reflection on how learning works. This is greatly supported by explicitly facilitating such reflections, e.g., as a discussion, as part of a lab report, or as a student presentation.

In preparing for the next iteration of the course, it is very helpful to ask guides to update their "list of good questions."

6 CONCLUSIONS

We investigated student perceptions and effective learning in combined basic- and advanced-level laboratory sessions, where students from the advanced course "guide" students from the basic-level course. Our case study shows that students learn from and with each other, which benefits both student groups.

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