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Integrating genuine research with laboratory teaching to motivate student learning

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Background and Problem formulation

“Cononical” laboratory exercises provide an important hands-on experience for students to have a real sense of the learnt knowledge while performing some pre-designed experiments with the expected results. It is anticipated that students both learn the skills and see by themselves the expected results, i.e. the textbook knowledge. However, both the teacher and the students have a feeling of the students just going through the exercises without learning much the skills and the knowledge behind. This fequently used teaching format thus could be very passive, boring and non-inspiring, therefore damaging the learning motivation of the students.

In the Molecular Microbiology MMI course that I led since 2019, such a teaching method was used in the lab exercise, and similar feedbacks from the students were observed. Instead, to improve the learning outcome of the laboratory exercises, I intended to integrate real research activity to the exercise, to motivate the students to think academically and critically. Looking back to the exercise acitivities, and reading up the teaching methods, it become obvious that such “inquiry-based” methods have been documented and used by other teachers, where the extent of the students engagement in research-driven activities can vary from some being very guided by the instructor to others being very open-ended with high student autonomy and responsibility (Adams, 2009; Cunningham et al., 2006; Howard & Miskovski, 2005; Rehorek, 2004; Russel & Weaver, 2008; Weaver et al., 2008).

It has been shown that students learn more if they "*read, write, discuss, or be engaged in solving problems...than just listen*" (Bonwell & Eison, 1991). Based on these findings, several teaching/learning activities (TLAs) were designed including group work/discussion and peer-teaching, collaborative and problem-based learning (Biggs & Tang, 2007). Via these, a constructive learning atmosphere is anticipated to increases students' willingness to engage in the TLA activity or problem-solving tasks and thereby their internal motivation for deep learning (Biggs & Tang, 2007).

The problem to address here is to increase students' motivation and engagement in the laboratory exercise, and deep learning is thus possible. Here the learning is not only of the empricial experimental skills, but also of a critical mindset to thinking about the project, the results obtained and its intepretation and integration with the prior knowledges the students already have. The logic behind is to first motivate the students and wake up their interest with the research based question. With that question on mind, one is then expected to actively find ways and tools to answer the question and thus learn the experimental skills while they approach the question. Below, I describe the changes that I introduced and the feedback from the students to evidence the benefits of the method.

Method: revision of *traditional* lab exercise to incorporate open-end research questions

1) Number of experimental exercises

Besides the format of traditional lab exercise, the exercise consisted of five different exercises that were performed simultaneously. A table map of the exercise activities is shown below (Figure 1), wherein different experiments were highlighted in differential colors. It is clear that the experiments were mixed up together and indeed students had to perform three experiments in a day. This had created great confusion for the students, who got lost easily and were simply dragged through the TLA activities.

To address these problems, I firstly reduced the number of experiments from five to three and changed the exercise to a three-week half-time format (Figure 2). First, this gave extra time of the students to actually think about, perform and digest/reflect on the relevant TLA activities; second, the schedule also fits the timelines of the new exercise.

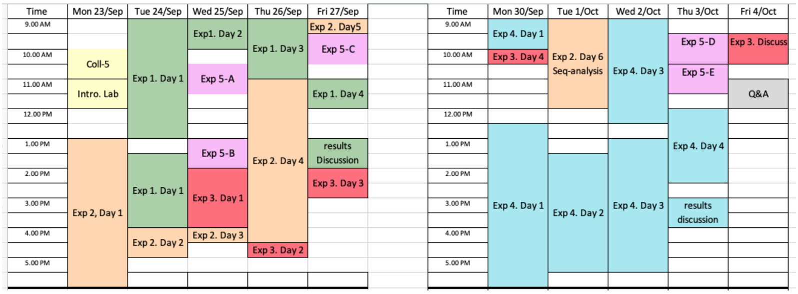

Figure 1. Schedule of old laboratory exercise. Different experiments are colored differentially. Note that, 2-3 experiments are often performed in the same day.

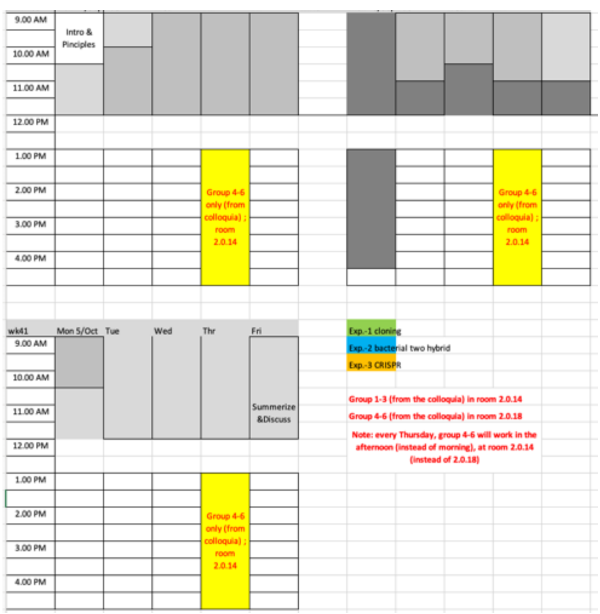

Figure 2. Schedule of revised laboratory exercise. Different experiments are colored differentially. Note that, now max. two experiments are performed in the same day.

2) Genuine research question of high importance and relevance to the MMI course

The new experiments include the molecular cloning of a protein SpoT. SpoT is an important protein in bacterial stress response, which is a core topic taught during the Lectures. Here I designed the experiments to study how SpoT interacts with ACP, an essential protein involved in fatty acid biosynthesis. SpoT interacts with ACP strongly; however, the interaction details remain unknown for thirty years now. SpoT is a large protein of 700 amino acids and thus hard to study exhaustively. However, it will be an ideal protein to use for laboratory teaching, since one can design a dozen of different single amino acid mutants of SpoT and ask the batch of students (ca. 30-40) to generate and test these mutants. For this I have designed a set of oligonucleotides to generate these mutant SpoT. Of note, these oligonucleotides are all different, and therefore the students perform the same cloning experiments (Exp-1, dark-grey, Figure 2) with the different oligonucleotides to generate different SpoT mutants at the end. When these mutants are obtained, the students could proceed to test their specific interactions with ACP by using the bacterial two hybrid technique in Exp-2 (light-grey, Figure 2), to study which amino acids of SpoT are essential for interacting with ACP.

3) Study groups: two-three students were grouped together to perform the exercise voluntarily and/or randomly, to encourage peer-learning/teaching and group discussions.

4) Streamlined exercises with integrated different skills and techniques

The core skills (underlined) to be trained via the exercise were kept via the above designed exercises and TLA activities. These include both empirical and in silico skills and activities (see attached laboratory manual). Briefly, the cloning step in Exp-1 include the PCR amplification of DNA, over-lap PCR to fuse together the mutant *spoT* DNA, restriction digestion of the mutant full-length *spoT* DNA, ligation of the digested *spoT* DNA mutants with the plasmid vector before transformation into a competence bacterial cell. Then, the correct plasmids will be confirmed first by colony PCR. Once a good colony was found, the plasmid inside will be purified and sent to a company to sequence its cloned region. When the result comes back, the students are taught to use the software Ape to analyze the sequencing results to confirm if the plasmids constructed are correct or not. If confirmed, the plasmids could be used in a second experiment to test its interaction with ACP. (If not confirmed, they can sequence a second potentially good colony; but, to keep up the pace of exercise, they can continue the exercise with the mutant generated from the other groups, which also served as biological replicates.) Of note, since these mutants were never generated before, it thus remains unknown if they still interact with ACP. Therefore, the students will observe the first-hand results themselves and make their own discoveries, which motivated them the most (see below).

5) Teaching/Learning Activities

- Principle discussion at the beginning, to give the overview of both the theoretical knowledge behind the project and also the technical roadmap to address the question, besides practical lab safety etc.
- Daily re-cap of the previous results, status and the tasks, principles and technical details related to the daily exercise
- Students performing the exercises, with peer- and group-discussion activities, including some ongoing questions listed in the lab manual for the students to discuss either before or after the daily exercise.
- Data sharing (e.g. via the Socrative tools) and discussion among the groups, across groups and with the teachers. These include the discussion of relevant questions listed in the manual.
- During the course, the teachers will teach the students to use softwares e.g. Ape and Pymol to analyze sequence data and visualize the mutations on the SpoT structure. The students got time to exercise the use of these softwares.
- Notebook writing: the students need to write down the result they obtained each day and summarize what they have observed, answer all relevant questions inside. They will hand in the report at the end, which will be assayed by the teachers.
- At the end of the exercise, we also proposed further open-end questions, for the students to thinking about. These will allow the students to actively think about the obtained results and further make their own experimental designs to address the new questions.
- Last day summarization: the teachers will organize discussions of both their obtained data, potential questions from the students. Furthermore, the teachers encouraged the students to present their ideas to design new experiments to address the last open questions. At least one technical roadmap will be presented by the teachers.
- Lastly, the teachers receive the lab notebook and will comment on them and give further advice on data analysis and academic writing. How-

ever, grades were not given to constitute the final grades of them, which has been a pity.

Results and course evaluations

First, after the change of lab exercise, the number of students who evaluated the course are significantly higher than before (26/35 vs 3-9/30 before), indicative of a more active participation in the class.

Second, in the course evaluation, when it comes to "what was good about the course" question, the comments (see below snapshots) are overwhelmingly about the laboratory exercise and are mostly positive. Although no further evaluation methods were used to get the feedback from students, during the TLAs, the teachers felt high enthusiasm from the students, since more were willing to ask questions when they had. This is interpreted as they've been motivated by the designed research-integrated exercise, and a nice working environment was established. Indeed, right from the beginning the students were told that they will start a research adventure that no one did before and knows the answer of; and during the exercise and at the end, they were told that the mutants they generated and even the results they produced will likely be used in real research project and scientific publications, and their names or academic-year/group names will be acknowledged.

1.1 What was good about the course? Why?

- *The lab teachers.*
  Godefroid: Very good teacher and great at explaining the theory behind the exercises. Always happy to answer questions in both Danish and English.

  Jakob: Also a very good teacher and didn't hestitate to help with any questions i had.
- *Yong was a great teacher, nice lab work, and overall very interesting.*
- *I think the teachers is good, but especially the course leader Yong. He is really passionate about teaching and the research in the field.*
- *The Lab course was good.*
- *Underviserne havde styr på hvad de snakkede om, og der var tydelig sammenhæng mellem det læste materiale, emnerne til forelæsningerne og colloquia.*
- *The colloquium was good, but there is way too many articles to read closely and study.*
- *Great help in laboratory 2.14 from the teachers*
- *It was great to be in the lab :)*
  Everything was done as well as it could have been done (considering the COVID). Very nice and helpful teachers.
- *The laboratory was great. Yong and Muriel were super cool and helpful.*

  Experience in the lab is very helpful for future jobs hopefully.
- *The course is very focused on central molecular mechanisms and very detailed. The reviews and original articles give good insight into the use and research of these mechanisms and are very applicable to the theory from the book.*

- *the laboratory exersices were very helpful and well organized. the lectures could be har to follow sometimes (maybe better if not on zoom)*
- *Gode forelæsninger og synes underviserene har været gode til at besvare diverse spørgsmål. Rigtig godt med tre uger i lab, med gennemgang af spørgsmål til de forskellige forsøg. Synes det har været super godt at der har været tid til at stille spørgsmål til øvelserne hvis der var*

ting man ikke forstod og at underviserene tog sig tid til at give en ordentlig forklaring

- *It was nice to have a lot of laboratory work enabling us to try the things we learned about in practice*
- *It was nice to tryout some different methods in the lab.*

  After laboratory the subject of the lecture seemed to be new and interesting things
- *Learning about relevant and new methods with teachers that are clearly knowledgeable about the subject is always welcome!*

Another observation of the student activation is from the practical supervision exercise of MMI, where both the pedagogical and department supervisors pointed out that the students were very active when they started the laboratory exercise, and they helped and communicated a lot with each other in a nice atmosphere.

Lastly, it can also be seen from the students' notebook (Figure 3) that they have very much engaged in the TLAs. For instance, one group (Panel A) depicted nicely the process to deduce one of the equations used to calculate how much of the DNA and the plasmid used for ligation. Another two groups (panels B,C) drew nicely how the mutations of SpoT were mapped on the structure of SpoT by using the Pymol software. The last group (panel D) showed clearly that the mutation exists in the sequencing result they obtained by using the Ape software.

In conclusion, this information altogether showed that research-integrated laboratory exercise did motivate more active participation of most students.

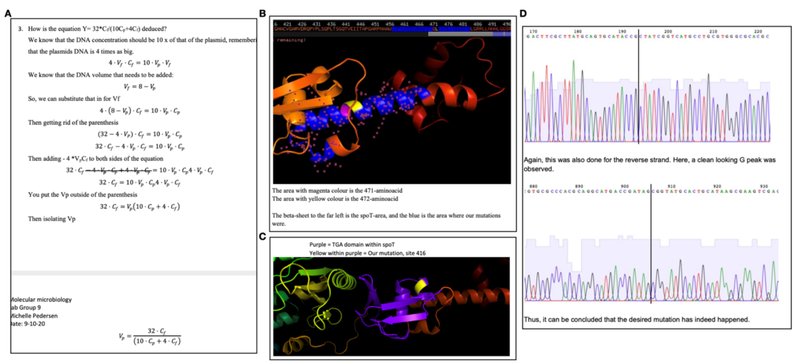

Figure 3. Snapshots of students' lab notebooks.

Conclusion and perspectives

The revised laboratory exercise organized the different skills coherently to address a real scientific question that is both important, unaddressed before, and relevant to the students' intended learning outcomes (ILOs) (i.e. know how to study protein-protein interactions). I believe these are the key element that make the students feel interesting, relevant and useful for their profession, which is also most motivating to them. The setting and conduction of the laboratory exercise also mimic real research activity inside most biology laboratories and thus prime them well for the future profession (as commented above by the students).

Although the above-described change of the laboratory exercise was made intuitively and even with practical reasons (i.e. to obtain mutant SpoT for real laboratory research), when looked back it more or less echoed the concepts stipulated in the field of pedagogical teaching (Howard & Miskovski, 2005; Jenkins et al., 2003; Russel & Weaver, 2008). For instance, the inquiry-based approach allows the students to participate in the generation of new knowledge and contribute to a larger research effort. During the exercise, the students' focus is directed away from the anticipated outcomes of the traditional laboratory exercises (i.e. knowledge acquisition) but rather towards the scientific processes of discovery (i.e. knowledge production). The students thus concentrate on performing the experiments, making their own observations, and collecting, analyzing and discussing data. If some experiments failed, they could also revisit the experimental setting and their own performance to suggest explanations and future improvement. Therefore, besides the experimental skills, the students got a chance to learn and experience how to study protein-protein interactions via the TLAs.

Further improvement and expansion of the exercise are possible. For instance, the students can be given more autonomy to start the exercise from making hypothesis and designing the experiments to address a given scientific question. However, this requires the students to have much more knowledge of the biological question and available techniques to use, which are often what the third-year bachelor students (the main population of students the MMI are targeting) need to learn. Despite this limitation, a guided exercise is still possible. For example, the teachers can expose the experimental designing process to the students and guide them to do so. Often some preliminary data and observations exist and serve as the start point for teachers to make some hypothesis and further design the exercise experiments to test this hypothesis. Similarly, the students could be given these preliminary data and observations, and a planned exercise process, i.e. a sort of theoretical or computer exercise, will be provided to guide the students to make the same or other hypothesis. However, given the limited time, the following pre-designed exercise experiments will be performed to just address the (most attractive) hypothesis made the teachers. In this way, the students will be trained with the (nearly) whole cycle of real scientific research process, i.e. analyzing data to make hypothesis, designing and performing experiments to test the hypothesis and obtain data, analyzing the obtained data to (dis-)approve the hypothesis and making new/next hypothesis, etc. The students thus can expect to transfer this real authentic research activity and ability to any other research topic in their future profession.

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