Högskolepedagogiska texter, Enheten för pedagogik och interaktivt lärande (PIL)
Göteborgs universitet, september 2015
www.pil.gu.se/publicerat/texter

The importance of laboratory exercises in biology teaching; case study in an ecotoxicology course

Bethanie Carney Almroth

University of Gothenburg

Institution for Biological and Environmental Sciences, Box 463, University of Gothenburg, Göteborg, Sweden 40530
bethanie.carney@bioenv.gu.se

Abstract: Laboratory exercises can be conducted according to number of different designs, chosen based on the specific learning goals. Here, expository and explicit reflective laboratory designs are compared, with the framework of a master's level course in Ecotoxicology with Physiological focus. Conclusions drawn from interviews with both teachers and students indicate that the explicit reflective laboratory design, with emphasis on student involvement the processes of natural science research including posing hypotheses, determining appropriate variables, data collection and analyses, and presentation of conclusions both written and oral, was preferred and more successful. Students were also able to gain a deeper understanding of subject matter and specific mechanisms, which are benefits normally attributed to the expository design.

Key words: Biology; Laboratory teaching; Inquiry based labs; Higher education; Science teaching

Introduction:

Students of biology are bombarded with new information, theories, techniques, concepts and vocabulary. In fact, some educational researchers postulate that students learn as many new terms in an introductory biology course as in a foreign language course. And these new terms are essential to learn in order to discuss the mechanisms and concepts of biological systems. However, rote memorization is a learning- and teaching method that is becoming more and more passé. Laboratory studies are often used in teaching natural science, especially a broad spectrum of biological sciences (Hughes and Overton, 2008). During the last 20-30 years, there has been a renewed interest in learning by inquiry, and in the use of laboratory work in demonstrating biological principles (see Handelsman, 2004 and references therein).

Laboratory studies can create a learning environment that encourages students to question, thereby fostering critical thinking. Students are often encouraged to work in small groups, leading to social interactions and peer teaching. In addition, students will gain technical skills and are often offered access to modern technologies. There are, however, possible pitfalls to this method of teaching. For example the teacher or students may place too much focus of technology or methodology, without time to interact or reflect on central ideas, thereby missing learning goals (Gunstone, 1991).

Specific learning outcomes with laboratory teaching include: conceptual understanding of subject matter, scientific reasoning skills, laboratory manipulative skills, and a better understanding of natural science research. It is important for students to gain understanding of, and experience in, several aspects of scientific research through the use of laboratory research in teaching. While the laboratory exercise should be designed to demonstrate a specific concept relevant to the current curriculum in the course, the students will also have an opportunity to gain knowledge and experience in other skills that are important to scientific research. This depends of course on the design and set up of the laboratory exercise as well as specific learning goals. This includes laboratory safety, bibliometry and literature searches, experimental design (for example, the importance of a properly designed control group), data collection and statistical analyses, interpretation of results within a context, written and/or oral presentation of findings. Students can be offered an opportunity to conduct 'real science.'

There are several ways to approach the use of laboratory studies in teaching biology. A common form of experimentation is expository instructions, where outcomes are well known and instructions are extensive (Schussler et al., 2013). While students will, to a high degree, achieve the correct results, they may not gain deep understanding of experimental design or even the biological concept the project is designed to demonstrate. Inquiry instruction, on the other hand, requires more active learning, and increased input from both students as well as teachers. Inquiry based laboratory instruction closely relates to problem-based learning (PBL), a teaching and learning strategy that has been used successfully in medical and natural science classes for decades (see Nowrouzian and Farewell, 2013, and references therein). Theories underlying PBL assume that learning occurs via constructivist processes, where-by students actively construct and reconstruct their knowledge via self-direction, in a social and collaborative context. New knowledge is contextualized into a previous framework, thereby facilitating comprehension, storage and recall (Dolmans et al., 2005).

A specific example from a master's level course in ecotoxicology, where laboratory teaching has been executed according to several different designs, will be presented and evaluated. The aim of this paper is to provide a summary of current pedagogical research on the benefits, and possible drawbacks, of using laboratory exercises in science teaching.

Case study in ecotoxicology:

Laboratory teaching comprises a large portion of the course, Ecotoxicology with Physiological Focus (app. 25% of time). This ecotoxicology course aims to explain how toxic compounds in the aquatic environment can affect living organisms. Between 24-30 students will take the course together. Student will learn which systems are affected following exposure to specific types of compounds, the modes-of-action of chemical toxicant groups, and specific endpoints that can be measured to assess effects of exposures. These laboratory exercises in this course are usually conducted during a two week intensive period with full days in the laboratory. All of the endpoints and methods to be used will have been discussed in the lecture portion of the course, prior to the laboratory exercise. Results from the experiments are written in the format of a research article, including a literature survey of the field, methods description, data analysis and presentation, and finally interpretation of results with respect to previous findings and possible impacts of current findings. These results are also presented to the class during an oral 15 minute presentation. Laboratory course has been set up with several different designs, described here.

- Expository Laboratory: Teachers design an exposure experiment and run this prior to the laboratory section of the course. Fish will be exposed to the compound(s) of choice, often a substance that is currently in focus in the media (for example bisphenol A or oil from car tires). Students will be involved in collecting tissue samples in an organized dissection. They will then prepare the samples according to step-by-step protocols, and measure predetermined endpoints under the guidance of teaching assistants. All students will measure the same list of endpoints in the samples, working in groups of four. Each teacher will be responsible for one method.
- Explicit Reflective Laboratory: Students are given the opportunity to design exposure studies, based on compounds of choice and exposure systems. They are presented with this opportunity at the start of the course and encouraged to read literature to help in

their decisions. They are also allowed to choose which endpoints they will measure, based on a list of methodologies available in our laboratory. Each teacher is responsible for a group of students, to help them with experimental design, choice of endpoints and to encourage reflection about the scientific process. Teachers will then guide the students through the laboratory exercises as above.

(Note: students are always offered the opportunity to run their experiments in in vitro cell-based systems as an alternative to animal research. All teachers are trained in animal ethics and handling, and all experiments are conducted with proper permits, under the guidelines of the animal ethics board of the University of Gothenburg and the Swedish Board of Agriculture.)

All of the teachers involved in the course aim to teach students specific laboratory skills, to help demonstrate concepts key to the course's subject matter, and to provide an opportunity to conduct 'real science', or level 3 on the Schwab-Herron scale. This is described in the explicit reflective laboratory set up. However, some of the labs have been organized on a lower level (0 or 1), as is described in the expository laboratory exercises. See table 1.

Table 1: Schwab-Herron scale (adapted from Schwab, 1962 and Herron, 1971)

Score	Problem	Means	Answers	Comment
0	Provided	Provided	Provided	Correct interpretations of achieved results are obvious; often used in labs to teach techniques.
1	Provided	Provided	Open	While problem and methods are provided, students are expected to find new relationships.
2	Provided	Open	Open	Students are presented with a problem but methods and answers are open to interpretation.
3	Open	Open	Open	Research question, methods and results are open; students are confronted with raw phenomenon.

I conducted interviews with three teachers involved in the laboratory portion of this course. This included the course leader and two additional teachers who have been involved in the course for 5 and 13 years, respectively. I also interviewed four former students, two of whom had taken the course with the first, expository set-up, and two of whom had taken the explicit reflective laboratory. There is an inherit bias in these student interviews, as these students had opted to continue their educations at the same institution, and were therefore already in general positive to the subject matter and department. Both groups were provided with the descriptions of the laboratory exercises, see above. I then asked their opinions on the two formats. Follow-up questions referred to possible benefits and drawbacks of either format. We discussed how they felt learning goals were achieved, whether students felt they were prepared for the work to be done, whether instruction was adequate, whether they felt they had acquired new knowledge, and if so, what sort of knowledge this was (i.e. technique based, deeper understanding of concepts from course, experience in the scientific process or 'real research').

Results:

The following excerpts from the conducted interviews are presented as representative of the comments made during the discussions. Some of the comments have been translated from Swedish to English (teacher 1 and teacher 2) and are therefore not direct quotes.

Impressions from teachers

The general response from the teachers interviewed was more positive towards the second format, in which students are encouraged to design and execute their own mini-projects.

> Teacher 1: One of the aims of the course, and the [explicit reflective] lab is to have students work with a real research project. I have a lecture at the beginning of the course explaining how we do research, starting with literature studies. We need to know what is already known. We go through experimental design, the importance of proper controls, statistics. And then presentation techniques. It is important to share results with others, to discuss results and defend conclusions. So the students are involved in a lot of the steps of 'real research'. They like this.
>
> Teacher 2: Ecotoxicology is much more than we can teach in this class. In using individual projects, we can also use the students to teach each other about other toxic compounds or mechanisms. They conduct literature reviews and then research projects that they present to each other at the final seminars. So the course content overall is improved by using the second type of lab.
>
> Teacher 3: Students think it is much more fun when they are involved in designing the project, when they get to do real research with real questions, and when the answers are unknown. And I think it is good for them to be involved in formulating a hypothesis, based on current knowledge, and then analyzing results, as they do in the [explicit reflective] lab. Do we see what we expected? Why or why not? Explaining unexpected results can be very informative too.

However, they were quick to point out possible problems and improvements.

> Teacher 1: The idea [behind the explicit reflective laboratory] was very good. But there was a big problem. We began the research projects at the beginning of the course. The idea was that the students would work with the research projects in parallel with the lectures. But we didn't structure their thinking and planning as much as we should have. We should start up day 1, schedule meetings after one week, where students can present their problem/questions and aims. We will need to have more meetings and follow up discussions. A second meeting should be scheduled to discuss experimental set up.

> Teacher 2: Another problem is that the students don't know the methods available. We need to be clearer in our lectures, describe which endpoints we measure, techniques we use. And since students work in groups, we need to make sure that all group members are following the project and participating.

> Teacher 3: They learn much more, this is evident in their reports and presentations, and even in the questions they ask, but we need to be very clear with expectations. Every student that comes in here wants to learn qPCR, but it is too expensive, time consuming and difficult method for a lab course. They don't always understand why one method may be equal to or better than another in answering a certain question. We don't choose methods a based on how cool they sound, but on what kinds of data we can gain, and how we can use that to answer the current question.

The teachers also discussed the expository laboratory format, a format which has been used less often in more recent years. This format is, in general, easier to teach since each teacher is responsible for teaching one technique in a 'station' and repeats the lessons 4-5 times in the different students groups. Results are known and easily explained. Students can also be positive to this format.

> Teacher 2: Students are often eager to learn new methods, and comfortable with cook-book labs. The labs concretize concepts that we teach during the lectures. Students can really get a feeling for how much they know and understand.

> Teacher 3: Students will often complain that it is not fair if the different groups learn different methods [as is common in the explicit reflective laboratory]. In this format all students learn all of the same methods.

However, teachers prefer to use the explicit reflective format for several reasons.

> Teacher 1: Laboratory experiments are expensive to run, and with budget cuts in time and money, we are not able to run labs as we would like to. If we use the teaching lab to test ideas within our funded projects, the lab becomes a win-win situation. We can run pilot studies, and students are involved in real research projects.

> Teacher 2: We often think that we are educating toxicologists. And then our students should be able to leave our program, and our class, and be able to get a job where they can handle

running their own experiments. Then it is important that they get a chance to do so before leaving the university.

Teacher 3: It's also boring for us to use the same labs every year! It feels like a waste of everyone's time. Those labs may demonstrate an important concept from the course but there are other opportunities to work with these concepts. Like in discussions about experimental design or interpretation of results. Even if a project has a different focus that the lecture material, I always draw parallels and use the teaching material to exemplify concepts we discuss.

Impressions from students

Students tended to be very positive towards the explicit reflective laboratory format. Many implied that lab work in previous courses had been 'boring' and un-inspiring. Students also emphasized that both formats could be used to demonstrate key concepts in the course but that the 'real research' also had the added benefit of allowing students to gain experience in the scientific process.

Student 1: good to conduct 'real research', set up our own projects. We don't have the opportunity to do this in other classes. But we need to spend more time reading articles and thinking and planning. All groups did learn the same basic methodologies, but we were able to choose specific methods for our own projects, which was good.

Student 2: All having same methodology is not important. Once you have basic laboratory skills you can always learn additional methods when needed.

Student 3: This lab (explicit reflective) was much more fun. It was the first time I enjoyed lab work. It was really interesting to delve deeper into a research issue.

Student 1: We enjoy working on our own projects, getting deeper into a subject. But we felt that we were given too much free rein and would have needed more a strict framework.

Student 4: Scientific method is something that we should already know at the master's level. But sometimes it's nice to get advice when an additional control, a positive control group or something like this, is necessary.

Discussion:

In general, both teachers and students were more positive to using explicit reflective laboratory exercises in teaching. As a strong tie between research and teaching is a goal outlined by the university, this type of laboratory is an excellent way to achieve this goal, provided it is structured and used properly. Students should be familiar with the nature of science, i.e. the manner in which scientific knowledge is constructed and validated, the work and methodologies of scientists, and the processes underlying evolution of scientific knowledge (Yacoubian & BouJaoude, 2010).

The students attending this course are on a master's level, and have therefore a strong base in molecular biology, chemistry or ecology. Their previous education and course work should have provided them with a stable context and well adapted system on which to construct the new information including in the learning goals of the ecotoxicology course. However, teachers will often assume this to be true and devise laboratory exercise studies based on these constructivist arguments (Kirschner et al., 2006). Care must be taken since novice learners, unfamiliar with basic laboratory practices, should be given direct instructions pertinent to the current exercises, including concepts and procedures (Sweller, 2003; Kirschner et al., 2006). Some studies have indicated that failure to do so, i.e. to use problem-based or inquiry-based teaching with novices, results in students that can become lost and frustrated, leading to confusion and misconceptions (Browne &Campione, 1994). It is therefore important that the teachers are aware of this, and provide enough instruction and feedback to keep the students on track.

There are several simple steps that can be observed to ensure that students are not falling behind during the experimentation. This is accomplished through discussions regarding purely methodological concerns (i.e. accuracy of measurements), calculations, as well as interpretation and discussion of results. These discussions should be firmly anchored in the information and concepts presented during the lecture portion of the course. With all this in mind, teachers can strive to increase cognitive activity of the students, and thereby learning via active processes, using concrete questions with this aim in mind (Shiland, 1999). For example, students can be asked to state the problem and hypotheses, identify relevant variables (as is the case in the explicit reflective lab), to predict possible outcomes and explain them, and so on.

Another important conclusion that can be drawn from the interviews is the fact that the students found the explicit reflective laboratory design to be more stimulating. Motivation, or interest in subject matter, is an important factor in learning (Schiefele, 1991). It is also possible that the strong ties between research and teaching not only motivates students directly, but also results in teachers that are more enthusiastic and therefore can more easily motivate students.

Theories of social constructivism are inherent in laboratory teaching strategies in this master's level course (Hofstein & Lunetta, 2004, and references there in). Students are expected to have basic knowledge of physiology and chemistry, as well as in the scientific process. While the written texts and lecture portion of the course help provide groundwork in central ecotoxicological theory and mechanisms, the laboratory portion of the class allows students to become engaged in their own learning processes (Shiland, 1999). These are further enhanced via peer teaching; all students must be able to explain their research hypotheses, the logic in asking a specific question, their choice of endpoints, functional physiological mechanisms explaining measured effects, as well as theory underlying analysis techniques. Interpretation of results occurs in a group setting where students are expected to question one another's findings, thereby encouraging their learning more about one another's projects. Moreover, engaging in scientific argumentation has been attributed to aiding students in developing deeper and more meaningful knowledge of scientific processes (Hofstein & Lunetta, 2004).

Several previous empirical studies have found that laboratory teaching based on inquiry-based learning is beneficial to students. Dresner et al. (2014) studied knowledge retention and higher level cognition in students prior to and after curricular reform. Their results indicated that inquiry-based field labs, organized into a structured scaffolding consisting of several courses, significantly improved students' ability to answer questions at higher levels of cognition and increased knowledge retention over time. Gasper and Gardner (2013) introduced authentic microbiology research into and introductory course using peer-led team learning workshops and focus on student feedback. They found that the research experience not only improved learning of course material, but also increased their level of critical thinking. In addition, students gained a deeper understanding of the nature of science (Yacoubian & BouJaoude, 2010), which will also be beneficial to them in their following coursework.

Finally, I would like to comment briefly on the use of inquiry-based laboratory exercises and relationship between research and teaching at a research-based university. Often times, focus is placed on the merits and prestige of research success but not on time and effort spent in educating the scientists of future generations (Anderson et al., 2001). However, implementing coursework that is strongly tied to the current research programs of teachers can be mutually beneficial to both the students and the researchers/teachers (Kloser et al., 2011). Students become engaged in authentic research based on an open-ended question, utilize modern techniques, collaborate with peers, and present results in a conference-like setting. The researcher(s) can in turn student-collected data into their research program. This relationship between teaching and real research is also a basis in the laboratory teaching exercises in the Ecotoxicology course discussed above, where students aid in and execute pilot projects within the framework of our current research platforms. However, it is important to follow a number of recommendations, such as those out forth by Kloser et al. (2011): use low barrier technical expertice, establish checks and balances for student collected data, use a diverse but constrained set of hypotheses, create a central database accessible by all students and teachers, use authentic scientific communication in course assessments, and allow teachers to utilize their specific fields of expertise to foster high-level discussions in both general biology as well as the specific research systems.

Conclusion:

This case study demonstrates, in accordance with current literature, some of the benefits of the explicit reflective laboratory in science teaching, and is therefore a way forward for the teachers in this course, and other biology course in which they participate. Carefully prepared laboratory exercises, with emphasis on inquiry-based, or problem-based learning, with attention to active learning under proper guidance, will allow students to construct deeper and longer lasting knowledge, as well as gain a deeper understanding of the scientific process.

References:

Anderson, W.A., Banarjee, U., Drennan, C.L., Elgin, S.C., & Epstein, I.R. et al. (2001). Science education, changing the culture of science education at research universities. *Science*, **331**, 152-153.

Dolmans, D.H.J.M., DeGrave, W., Wolfhagen, I.H.A.P., &Van Der Vleuten, C.P.M. (2005). Problem-based learning: future challenges for educational practices and research. *Medical Education*, **39**(7), 372-741.

Dresner, M., De Rivera, C., Fuccillo, K.K., & Chang, H. (2014). Improving higher-order thinking and knowledge retention in environmental science teaching. *BioScience*, **64**(1), 40-48.

Gasper, B.J. & Gardner, S.M. (2013). Engaging students in authentic microbiology research in an introductory biology laboratory course is correlated with gains in student understanding of the nature of authentic research and critical thinking. *J Microbiology and Biology Education,* **14**(1), 25-34.

Gunstone, R.F. (1991). Reconstructing theory from practical experience. In: BE Wollnough (Ed.) *Pratical Science*, Milton Keyes, Open University Press, pp- 67-77.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentil, J., Lauffer, S., Stewart, J., Tilghman, S., &Wood, W. (2004). Policy Forum: Scientific teaching. *Science* **304**, 521-522.

Herron, M. (1971). The nature of scientific inquiry. *School Review* **79**, 171-212.

Hofstein, A. &Lunetta, V. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science education* **88** (1), 28-54.

Hughes, I. & Overton, T. (2008). Key aspects if learning and teaching in science and engineering. In: *A Handbook for Teaching and Learning in Higher Education*, 3rd Edition, Kogan Page, pp. 226-245.

Kirschner, P., Sweller, J. & Clark, R. (2006). Why minimal guidance during instruction does not work: an analysis of the failure of constructivist discovery, problem-based, experimental, and inquiry-based teaching (2006). *Educational Psychologist,* **41** (2), 75-86.

Kloser, M.J., Bronwell, S.E., Chiariello, N.R., & Fukami, T. (2011). Integrating teaching and research in undergraduate biology laboratory education. PLOS Biology, **9**(11), e1001174.

Nowrouzian, F.L. & Farewell, A. (2013). The potential improvement of team-working skills in Biomedical and Natural Scienc students using a problem-based learning approach. *J. of Problem Based Learning in Higher Education*, **1**(1) 84-93.

Schiefele, U. (1991). Interest, learning, and motivation. *Educational Psychologist*, **26**(3-4), 299-323.

Schussler, E., Bautista, N., Link-Pérez, M., Solomon, N., & Steinly, B. (2013). Instruction matters for nature of science understanding in college biology laboratories. *Bioscience* **63**, 380-389.

Schwab, J.J. (1962). The teaching of science as enquiry. In Th teaching of Science, eds JJ Schwab and PF Brandwein. Cambridge, MA, Harvard University Press, pp 3-103.

Shiland, T. (1999). Constructivism: The implications for laboratory work. *J of Chemical Education*, **76**(1), 107-109.

Yacoubian, Hagop, BouJaoude, & Saouma (2010). The effect of reflective discussion following inquiry-based laboratory activities on students' views of nature of science. *J Research Sci Teaching,* **47** (10), 1229-1252.