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Fungi are characterized how...? Implementing inquiry-based learning in a laboratory exercise.

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Introduction

Laboratory exercises have great potential for conveying scientific principles, for development of critical thinking skills and for fostering deep learning. A common misconception of laboratory exercises is that their teaching potential is intrinsic —that students engaged in activity or hands-on learning are by default learning as intended (National Research Council Committee 2000). More accurately, the teaching potential of laboratory exercises is highly dependent on how the activity is designed and how the information is conveyed.

In traditional pedagogics, laboratory exercises use kit-based or cookbook approaches where students simply follow a recipe and record data. Students usually proceed through such a predefined and rigid exercise without a clear understanding of the purpose behind each step (Hofstein & Lunetta 2003). These cookbook exercises represent a type of direct instruction method where the laboratory manual or teacher lays out a set of prescribed activities with no possibility for independent thinking. An inherent problem with direct instruction is that it leaves little opportunity for problem-solving and higher-order critical thinking skills, both of which are implicated in deep learning, knowledge retention and development of scientific inquiry skills (Halme et al. 2006, Biggs & Tang 2011*a*). Direct instruction education may result in an accumulation of knowledge but it does not necessarily lead to a firm grasp of the topic or key concepts nor does it lead to skills development.

Among the first to acknowledge the limits and drawbacks of direct instruction pedagogy was John Dewey. Dewey wrote extensively on the philosophy of education and on the theory of inquiry (Dewey 1938). He was a pioneer of and major advocate of inquiry-based learning.

> "Before 1900, most educators viewed science primarily as a body of knowledge that students were to learn through direct instruction. Dewey contended that science teaching gave too much emphasis to the accumulation of information and not enough to science as a way of thinking and an attitude of mind. Science is more than a body of knowledge to be learned," (National Research Council Committee 2000, p. 14)

Inquiry-based teaching is a pedagogical method that promotes learning by guiding the student toward the resolution of a problem or problems. In inquiry-based teaching the instructor serves as a facilitator rather than a mere deliverer of information. The student, in collaboration with their fellow student(s), observes, hypothesizes, investigates, interprets, shares authority for answer(s) and as a result, is empowered to ask additional questions. This is in stark contrast to the traditional teaching method where students routinely memorize information and complete specified tasks and where the authority for answers remains solely in the teacher's court. Inquiry-based learning is best represented as a cycle (Figure 6.1) which involves questioning, investigation, project creation and cooperative learning through discussion and reflection. A central tenet of inquiry-based learning is that this cycle is continuous and that successful inquiry leads to the ability to ask more questions (Koschmann 2013). This cycle can be used as a basic model for designing inquiry-based laboratory exercises.

Inquiry-based learning is a successful strategy that has been shown to significantly improve performance on assessment questions (Rissing & Cogan 2009). Despite its success and promise, inquiry-based teaching remains more of an alternative teaching method rather than the standard in educational institutions (Brainard 2007). One of the reasons that inquiry-based teaching is not more prevalent is because it is thought to be too difficult to implement. In addition, there is a misconceived notion that the principles of scientific inquiry and inquiry-based learning are only applicable to the discipline of science.

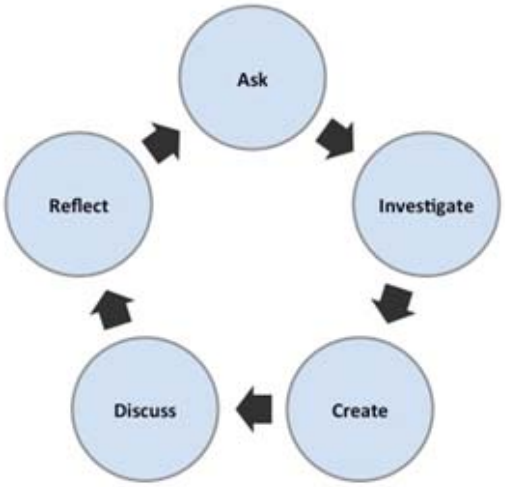

Fig. 6.1. The cycle of inquiry based learning. (adapted from http://chipbruce.net/resources/inquiry-based-learning/defining-inquiry-based-learning/)

Project Description

The purpose of this project is to implement inquiry-based teaching to the Masters level course *Biological Control of Pests* (5440-B2-2E14) which is taught annually at the Department of Plant and Environmental Sciences at the University of Copenhagen. The course, *Biological Control of Pests*, is run by a single professor; however, additional professors as well as post-docs and PhD students participate in teaching several of the exercises and lectures.

This project focuses on the revision of one laboratory exercise, *Characterization of Fungi*, which was previously taught by other post doctoral researchers and instructors other than myself. The objective of the exercise, *Characterization of Fungi*, is to demonstrate what can be discovered about insect pathogenic fungi through molecular characterization, i.e. DNA sequencing and analysis. In past years the exercise followed a strikingly traditional, cookbook format with no opportunity for inquiry or for critical thinking; it was setup so that students are given an unknown fungus and over two course days are instructed to extract, amplify and sequence its DNA by following a very specific set of mostly kit-based instructions. As the exercise is, the students largely experience the tedium of kit-based instructions rather than excitement of inquiry and hypothesis testing.

Two goals in revising this exercise are to turn it into a more accurate representation of how an insect pathologist would characterize a fungus in

their everyday research — a process that is naturally inquiry-based, and to include inquiry-based activities for teaching the principles of not only the topic *Characterization of Fungi* but also the principles behind the methods. The purpose of the later is to equip the students with methodological problem-solving skills, which are as much a part of scientific inquiry and inquiry-based learning as are hypothesis formulation and hypothesis testing.

Implementation

One of the difficulties in improving *Characterization of Fungi* is that the main focus of the exercise, molecular characterization, from start to finish is very time-consuming yet the entire exercise must be completed in two, short, four-hour course days. In previous years, both course days have run over the allocated time. In redesigning the exercise I opted for quality over quantity, for removing activities, e.g. kit-based activities, or steps with low teaching potential and with a correspondingly inefficient use of time. These steps, although not omittable in everyday research, were viewed as an impediment to the incorporation of problem solving or critical thinking activities. The primary goal of my project, to make the exercise inquiry-based was partly achieved by presenting the students with a real-life problem that could be solved through guided steps and collaboratively with their classmates.

Part1. Problem formulation and setting the stage for inquiry

With the extra time afforded by the exclusion of the kit-based exercises I was able to include a morphological component which in turn set the stage for the entire exercise. The addition of the morphological component made the exercise more true to the day-to-day experiences of an insect pathologist in biological control (the course topic); as a result the steps and premise of the exercise were more logical than in the pre-revised exercise. This morphological component included unknowns which served to formulate the initial problem and which formed the basis for subsequent activities.

Part II. Stimulating inquiry with unknowns

Traditionally, morphological characterization in a laboratory exercise involves making guided, step-by-step observations of the organism whose identity is given. I avoided direct instruction by designing the exercise so that the students were presented with five unknowns and provided with the tools, e.g. guided observation and a dichotomous key, to identify the unknown organisms. The students were instructed to first individually record their basic observations for each unknown and then work in groups of three or four. By including unknowns that now essentially belonged to the students, the problem became a tangible one and promoted further inquiry and curiosity. *Were their identifications correct? What would the molecular data reveal about the fungus they observed, described and identified earlier?* (see Appendix A)

Part III. Exercises for the exercise: implementing short inquiry-based activities for teaching the principles behind the methods.

Laboratory exercises all require the inclusion of a step-by-step instructional part at some point. In *Characterization of Fungi* the step-by-step instructional component was reached at the end of the first day in the molecular characterization section. To encourage the students to think about the steps and to understand the principle behind the methods I developed two short inquiry-based exercises for them to include in the step-based experimental setup (see Appendix B). The students were asked to come up with two hypotheses, which were subsequently tested in the process of following the cookbook protocol. To be able predict the outcomes or formulate the hypotheses the students had to first grasp the basic principle behind the methods. In contrast to previous years, the step-by-step section in this revised exercise purposely left open the possibility for negative results and failed experiments. These negative results and failures were subsequently discussed as a class and used to enrich the learning experience.

Part IV. Metacognition: the application of learning

On day 2, the laboratory exercise ended with several questions, some of which were open ended. The purpose of these questions was to give the

students an opportunity to reflect on the exercise and their results and to discuss their thoughts and solutions with their classmates. In addition, two homework questions were given (see Appendix C). The purpose of the homework assignment was partly to encourage metacognitive thinking. The question posed in the homework assignment required the students to integrate the knowledge gained from the current exercise with the knowledge gained from previous lectures and exercises in the course. The question describes a real-life problem for which the students could now propose an educated solution. The answer to this question could be unique; it relied on the accumulation of knowledge and had no predefined right or wrong answer. The goal was that the students felt ownership for the answer and became aware of their accumulated knowledge.

Conclusions

The successes and benefits

Designing a laboratory exercise with inquiry-based teaching is undoubtedly more laborious than simply providing a list of tasks for the students to complete; however, the benefit of teaching through inquiry is that the students appeared to remain clearly engaged and enthusiastic over both course days. Students asked thought-provoking questions and initiated discussions with their classmates as well as with me. I found the role of facilitator rather than deliverer of knowledge more rewarding and more interesting. In addition, the students provided thoughtful, intelligent answers to the homework questions. It was clear that they grasped the concepts and made connections between this exercise and previous work in the course.

A summary of the key inquiry-focused differences between the original exercise and the inquiry-based exercise is provided in Table 6.1. Overall, the goal of the project was achieved. Inquiry-based teaching in the laboratory exercise Characterization of the Fungi was successfully implemented.

The challenges

Implementing inquiry-based teaching successfully has its challenges. One such challenge is estimating how much time to allocate for the inquiry-based activities. For instance, even though I omitted some of the activities from the original exercise, the revised exercise exceeded the time slot

on both days by 10–15 minutes. Inquiry-based exercises requires a lot of time. The limitation of time presents another challenge —filtering the information: if quantity is exchanged for quality, what should be included or omitted? On what activity should the time be focused and why? How can inquiry-based learning of the methodology be incorporated?

Table 6.1. Comparison of the characteristics of the standard protocol from previous years and the newly implemented inquiry-based protocol for the exercise *Characterization of Fungi*.

Characteristic	Standard	Inquiry-based
Problem formulation	**Yes** (provided by teacher)	**Yes** (partly conceived by the student)
Hypothesis testing	**No**	**Yes**, more than once
Independent observation	**No**	**Yes**
Attention to the concepts behind the methodology	**No**	**Yes**
Number of questions posed	**0**	**29**
End assignment a written report of results and methods	**Yes**	**No**
End assignment an open-ended question with a clear link to the knowledge gained from previous lectures and exercises in the course	**No**	**Yes**
Student ownership of answers to problems	**No**	**Yes**
Trouble-shooting skill development	**No**	**Yes**
Critical thinking exercises	**No**	**Yes**
Group work	**Yes**	**Yes**
Collaborative problem-solving built into exercise	**No**	**Yes**

A Appendix I

[Truncated excerpts from day 1 of Characterization of Entomopathogenic Fungi laboratory manual. Pedagogic focus: problem formulation, setting the stage for inquiry with unknowns.]

This laboratory exercise is divided into two parts.

- In the first part of the exercise you are going to identify the fungi from infected beetle larvae, flies and bees. The goal of this part is for you to observe the fungi and become familiar with them. By the end of the exercise you should be able to:
  - recognize the genera *Cordyceps (Beauveria), Metarhizium*, an entomophthoromycotan fungus and a bee infected by *Ascosphaera*
  - identify a spore discharge setup and if spores from an entomophothoromycotan fungus have been discharged onto a slide
- In the second part of the exercise you will test if you have correctly identified the fungus you chose as *Cordyceps* and determine it species by amplifying its DNA and then analyzing the sequence.

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Part 1. Morphological Characterization

Here you will learn to recognize members from each of the three of the major groups of insect pathogenic fungi: Entomophthoromycota, Hypocreales, Ascosphaerales. This part is titled morphological characterization but this is a bit of a misnomer because the dichotomous key below includes couplets that rely on ecological characters, on host identification, and on the method of spore discharge. In insect pathology these characters can be just as important as morphological characters and are very useful for narrowing down which fungus you have.

There are 4 fungi for you to identify

Work in groups of 2–3. Before you begin preparing slides write down a brief description of each fungus in the spaces below. Be sure to record your observations in the space that corresponds to the fungus you are looking at e.g. *Fungus 1* observations in the *Fungus 1* space

Prepare a slide for each of the 5 fungi. Divide the work up among your group members.

1. Add a small drop of water to a microscope slide.
2. Pick up a small amount of the fungus from the insect.
3. Place the fungus in the water droplet on the slide.
4. Place a coverslip on top.

Fig. 6.2. Appendix I - (continued)

Fungus 1	
Macroscopic observations: Host/substrate: Color of culture: N/A Color of spores: Forcible spore discharge?	**Draw what you see in the microscope.**
Fungus 2 …	

Dichotomous key

1. Host a fly **2**

1. Host not a fly or host unknown ..... **…3**

2. Conidia forcibly ejected, spade shaped, large .... ***Entomophthora muscae***

2. Conidia not forcibly ejected, spherical, small ..... ***Cordyceps* (*Beauveria*)**

3. Host a bee larva, larva mummified, black; spores in sporeballs .....
..... ***Ascosphaera aggregata***

3. Host not a bee, isolated from soil **5**

4. Conidia cylindrical, formed in parallel chains ..... ***Metarhizium***

4. Conidia spherical, not formed in parallel chains .....
..... ***Cordyceps* (*Beauveria*)**

Record your identification for each of the 5 fungi.

Fungus 1 = _____

Fungus 2 = _____

Fungus 3 = _____

Fungus 4 = _____

Fungus 5 = _____

B Appendix II

[Excerpts from day 2 of Characterization of Entomopathogenic Fungi laboratory manual. Pedagogic focus: implementing short inquiry-based activities for teaching the principles behind the methods.]

Brief exercise on gel electrophoresis.

In one of the lanes on each gel I added 5 μl of green food coloring. This food coloring is composed of two molecules: Lutein (a plant derived yellow pigment) and Brilliant Blue (a synthesized pigment). The molecules are pictured below. Which of these molecules do you predict will travel faster in the gel? Why? Write down your hypothesis in the blue box on the next page.

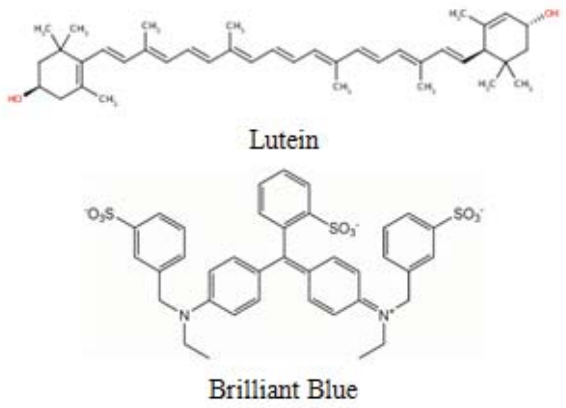

Fig. 6.3. From: Brief exercise on gel electrophoresis

Hypothesis :

Results : Which molecule traveled further?

Conclusion : Was your hypothesis supported? If not, offer an explanation for your results.

1. Identify the denaturing, annealing and elongation steps in the PCR you are running.

PCR Conditions			
Machine/Program:	*T-gradient Nicolai/ Touch B2*		
TD-PCR			
98°C	30 s		
98°C	10 s		
70–60°C	30 s	**10 x**	reduce temperature by 1°C per cycle for 10 cycles
72°C	30 s		
98°C	10 s		
60°C	30 s	**38 x**	
72°C	30 s		
72°C	10 min		
10°C	4-ever		

Fig. 6.4. Appendix II. (continued)

2. In the PCR you included a DNA extract from Ascosphaera. Do you expect this DNA to be amplified? Why or why not?

C Appendix III

[Excerpts from day 2 of Characterization of Entomopathogenic Fungi laboratory manual. Pedagogic focus: metacognition.]

Answer the following questions in class.

1. Identify the major groups on the tree. Look at the Excel sheet. The groups are color coded. In which group does your fungus belong?
2. Base on the features of other isolates in the group that your fungus belongs to, what can you predict about the isolate you have?
3. What does the sequence data tell you that you would not have known based on morphological features alone?

Work on questions A) and B) below at home. You may work in groups. Post your answer in Absalon.

A). In Lecture 2 of this course you learned about the beetle *Melolontha* that causes damage to the roots of christmas trees. Suppose that these twelve isolates of *Cordyceps* from the previous steps (i.e. Excel sheet) were all collected from a christmas tree farm. If you wanted to develop a biological control product for *Melolontha* from these isolates which group of isolates would you begin screening from? In a paragraph or so, explain what you would do and why. Think about where you would apply the biocontrol product. Would you mix it in with the soil or would you apply it to the above ground parts of the tree? Think about where the target pest lives. Would you consider UV resistance a more important trait than virulence? Could you modify the environment somehow (i.e. conservation biological control) to favor the prevalence of the less UV resistant but highly virulent genotype?

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[To answer question A) the students apply what they learned in at least three of previous course days in addition to what they learned in this exercise]

All contributions to this volume can be found at:

http://www.ind.ku.dk/publikationer/up_projekter/2015-8/

The bibliography can be found at:

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