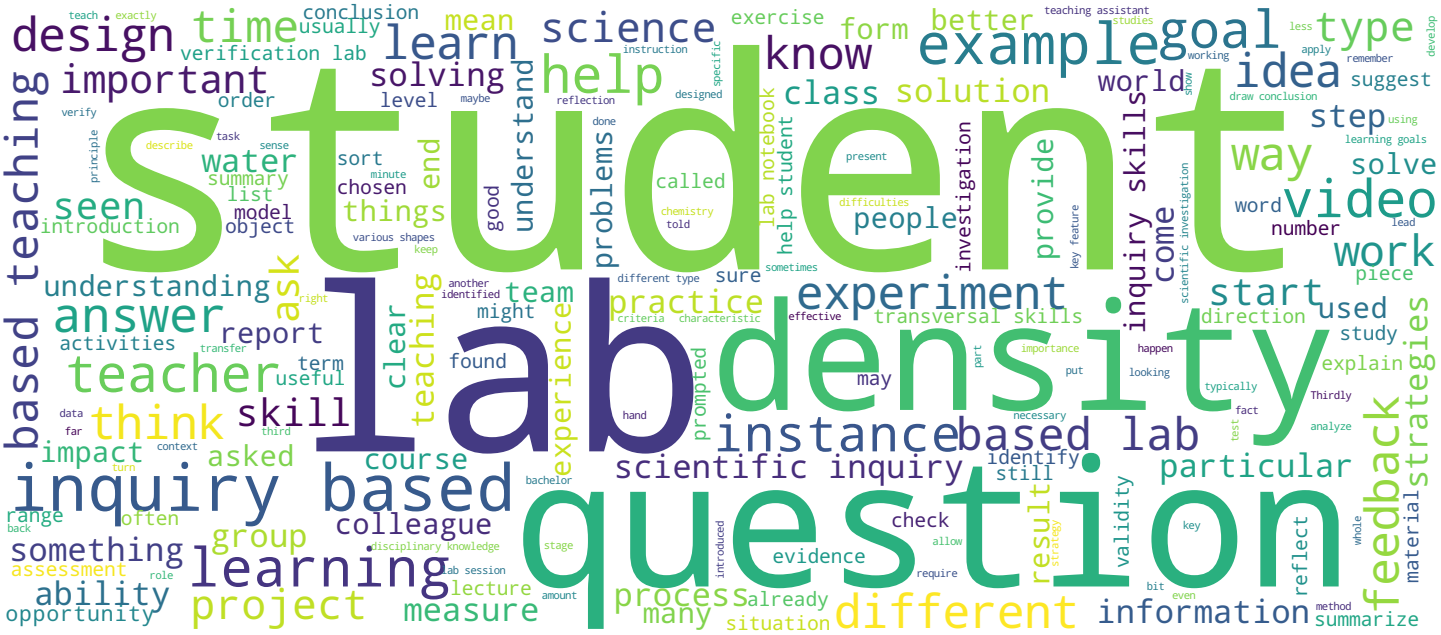
Labs: What do we want students to learn?

Foundations for Teaching in Higher Education

Roland Tormey
Ingrid Le Duc
Cécile Hardebolle

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



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Video

EPFL

What do we want students to learn from labs?

Experimental work is an important component of the science & engineering curriculum. Whether at the bachelor or at the master level programs generally embed a high number of lab sessions. When thinking about the examples of lab sessions, you might have the image of the chemistry or physics lab but actually labs are common learning activities in all disciplines including architecture or engineering. So, given the central place of labs in the science and engineering curriculum, a very fundamental question that you have to ask your self is; what do we really want students to learn from labs?

Notes

Summary

0m 04s

Goals for this video

- Identify and categorize the different **goals of labs**
- Describe what is **inquiry**, illustrate what are **inquiry-based labs** and list their main characteristics
- Present evidence of the **impact** of inquiry-based teaching **on learning**

At the end of this video, you will be able to first identify & categorize the different goals of labs. Then you will be able to describe what is inquiry and what are inquiry-based labs and their main elements. Finally, you will be able to present evidence about the impact of inquiry-based teaching on learning.

Notes

Summary

0m 45s

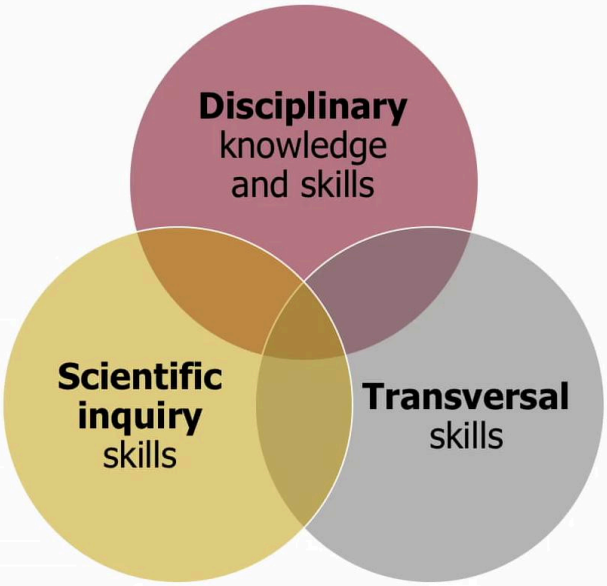
So, what are the goals of labs? I suggest that you stop this video for a minute and think about the goals you see for labs to help you with this task, it can be helpful to take an example of a lab that you have supervised or that you will supervise and to use this example to list the different learning goals involved. Make sure to write down all the goals you think about, on a piece of paper, then start again the video.

Notes

Summary

1m 07s

What are the goals of labs?



National Research Council, 2006
Hughes and Ellefson, 2013

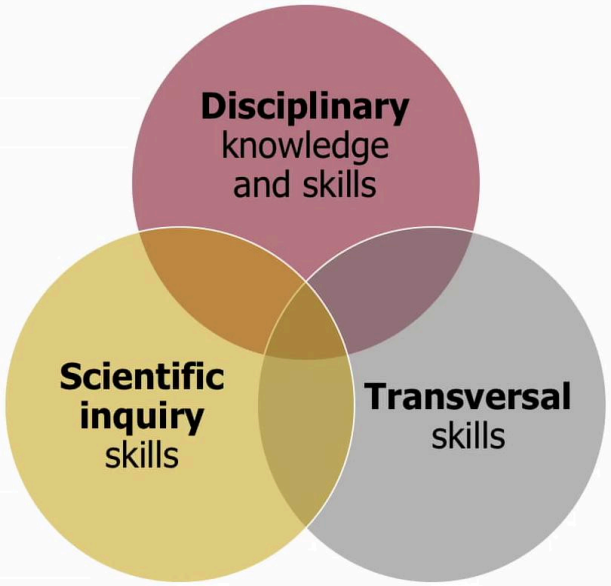
If you ask different persons around you what they think are the goals of labs, it is very likely that you will get a wide range of responses. As noted by the National Research Council in their America's Lab Report in 2006, there is a lack of agreement among teachers and researchers on the goals of labs. These typically include goals relating to the disciplinary knowledge & skills such as; deepening students' understanding of the subject matter learnt in the lectures or familiarize students with the laboratory techniques use in that discipline. They also usually include transversal skills such as; developing team work abilities, learning to write reports, or learning to keep a lab notebook. But as Hughes & Ellefson underline, what is really unique about the lab experience is the opportunity to practice applying the scientific method, to learn the scientific inquiry skills. ' National Research Council even emphasizes that labs should drive students to understand the complexity and ambiguity of empirical work and to help them to develop an understanding of the nature of science.

Notes

Summary

1m 35s

What are the goals of labs?



National Research Council, 2006
Hughes and Ellefson, 2013

So, if we summarize, the goals of labs are actually three fold and all three categories are important, deepening disciplinary knowledge and skills, developing transversal skills, but more importantly, developing scientific inquiry skills. Now I suggest that you take one minute to categorize the goals you have listed on your piece of paper previously, which of them relate to disciplinary knowledge and skills, to transversal skills, or to scientific reasoning.

Notes

Summary

2m 49s

A characteristic of labs on which teachers usually agree is that there should be an opportunity to engage students in hands-on activities, which include, for instance, the manipulation of technical equipment, whether there be lab tubes, complex specialized machines or computers. This is why labs are regarded as a type of 'learning by doing' setting. But how do we design labs that allow students to learn science by doing science?

Notes

Summary

3m 23s

Ingredients of labs – Example: density

Summary of what is density and the density equation

Determine experimentally the density of objects with various shapes

Implement a described setup, realize series of defined measurements

Background / Introduction

Goal / Question

Investigation

I will now present the main element that are commonly seen in labs and illustrate them with an example of a lab on density. I have chosen this example because we have all learnt what density is in high school, so we can actually concentrate on the design of the lab instead of concentrating on the topic of the labs. So, usually labs start with an introduction which provide some background for the lab topic, either as a summary or as a compliment, to what has been seen by students in lectures. A lab on density could typically start with a summary of what is density and the density equation. Then comes the goal of the lab, which can sometimes also take the form of a question. A goal for a lab on density could be to determine experimentally the density of different objects with various shapes. To reach this goal, students have to do some sort of scientific investigation, which usually includes carrying out an experiment, collecting and analyzing some data. In the lab on density, students would typically get instructed to measure the mass and volume of objects with regular shapes and then to calculate the density using the formula.

Notes

Summary

3m 52s

Ingredients of labs – Example: density

Verify experimentally the theory presented in the lectures *(deductive)*
=
Verification Lab

- Background / Introduction
- Goal / Question
- Investigation
- Conclusion & reflection

Communication of results

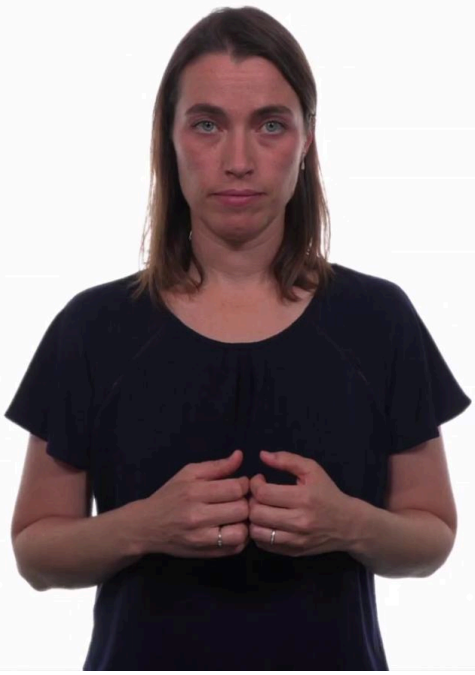
For objects with irregular shapes they would be instructed to determine the volume of the object by putting the object into water and then measure the amount of water that it displaces. After the experiment, students are usually invited to conclude or to answer some questions, that are designed to make them reflect on what they have learnt. So, for instance, after having measure the density of several objects made of the same material but with various shapes, students could be prompted to notice that density is independent of the quantity or shape of the material. This would lead them to verify that the density is an intensive property as they have been told in class. Documenting the work is usually a component throughout the whole lab work and students are often asked to complete a lab notebook and to write a report that typically get graded. To check for yourself that this structure also applies to labs in higher education an exercise that you can do is to take the work sheet of a lab that you teach or will be teaching and to see if you can identify these elements in the texts, for instance. Now let's step back and analyze a bit more this example.

Notes

Summary

5m 12s

Ingredients of labs – Example: density



Verify experimentally the theory presented in the lectures *(deductive)*
=
Verification Lab

Background / Introduction

Goal / Question

Investigation

Conclusion & reflection

Communication of results

What students are actually asked to do in this density lab is to verify that something they have been taught in class as a theory applies into practice. In the literature, this type of lab is called a "verification lab" because it follows a detective logic where students get told what is the general rule and then apply it to specific examples in the lab. If you think about the learning goals, we have discussed previously for labs, verification labs can be a good way for students to deepen their understanding of the course content and also to develop transversal skills such as writing reports. However, this type of lab usually does not really help the students to develop scientific inquiry skills, because they do not get to experience how scientists actually do science.

Notes

Summary

6m 32s

How do scientists do science?

Inquiry

- Identify scientific **questions**
- **Design** and conduct investigations
- Draw conclusions supported by **evidence**
- **Critically assess** these conclusions
- **Communicate** results

Adapted from Minner et al., 2010

The way scientists do science calls upon a range of core skills including the ability to ask questions about the world, the ability to design and to conduct investigations using scientific methods, to try to answer those questions, the ability to draw conclusions based on the evidence generated by an investigation, the ability to critically assess these conclusions in light of alternative explanations and then to to communicate and justify the proposed conclusions. The idea of inquiry based labs is to provide students with the opportunities to exercise exactly these skills, which form the basis of scientific inquiry.

Notes

Summary

7m 27s

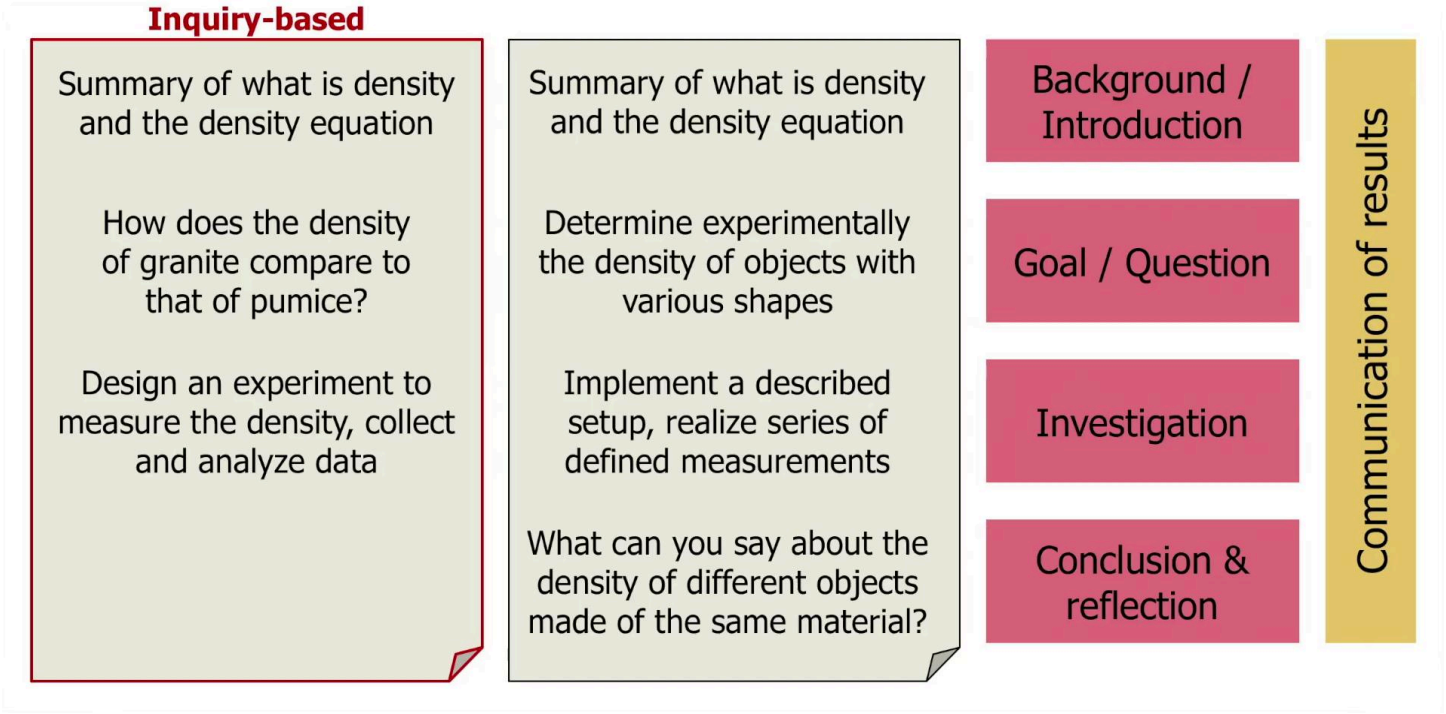
In other words, the idea of inquiry-based labs is to have students learn science by doing science, the way scientists do it. So, what do inquiry based labs look like in practice?

Notes

Summary

8m 15s

What do inquiry-based labs look like?



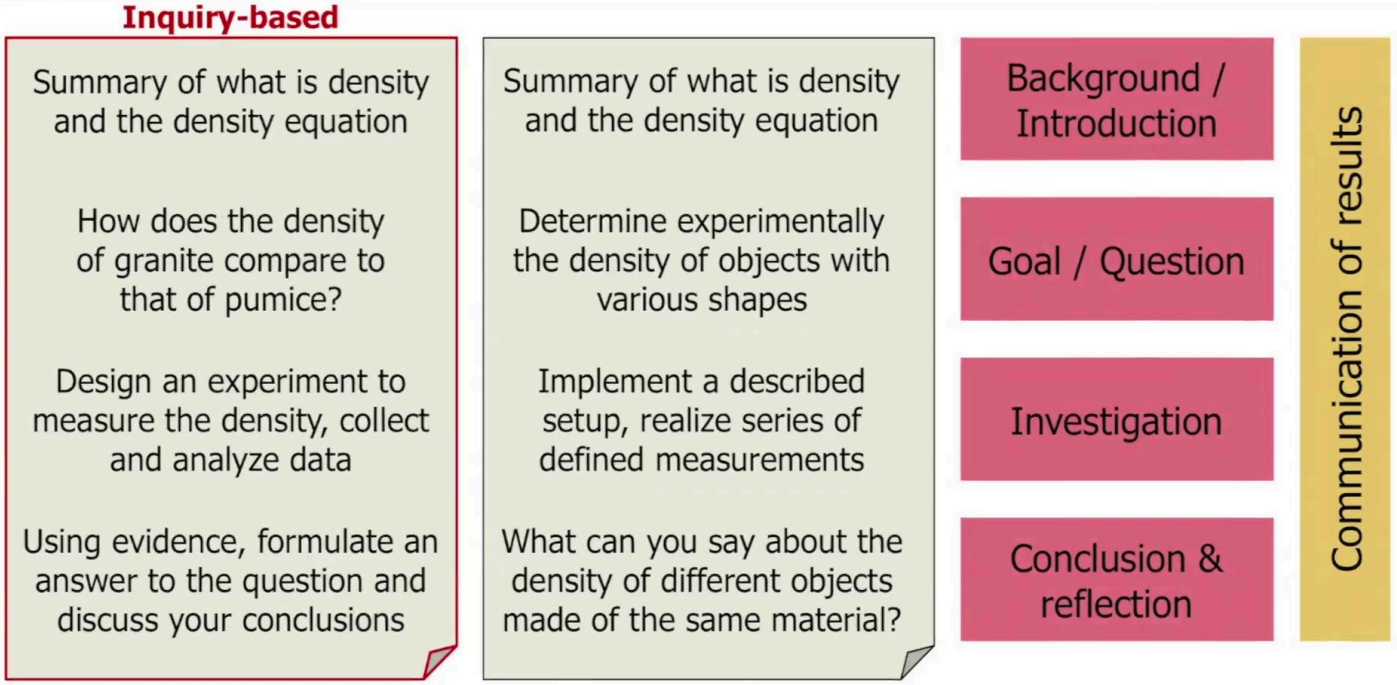
Let's take again the example of our lab on density and see what would an inquiry-based version of this lab look like. Our first thing to highlight is that it would have the same basic ingredients as we have seen before with an introduction, a goal, an investigation, a conclusion and the communications of the results. Actually, the introduction could even be exactly the same as in the verification lab, with the summary of what is density and the density equation. But then the goal of the lab would not be to determine experimentally the density of different objects with various shapes but instead students would be given a question about the world around them. For instance, how does the density of granite compares to that of pumice? A key feature of this question is that the students don't know the answer in advance. But they can be prompted to predict the answer and then ask to design an experiment that would allow them to check their prediction. Designing an experiment to measure the density of these two types of stones necessarily leads students to interrogate their understanding of density with a range of sub-questions. For instance, how to measure density when the sample does not have a regular shape which is a case of premise?

Notes

Summary

8m 29s

What do inquiry-based labs look like?



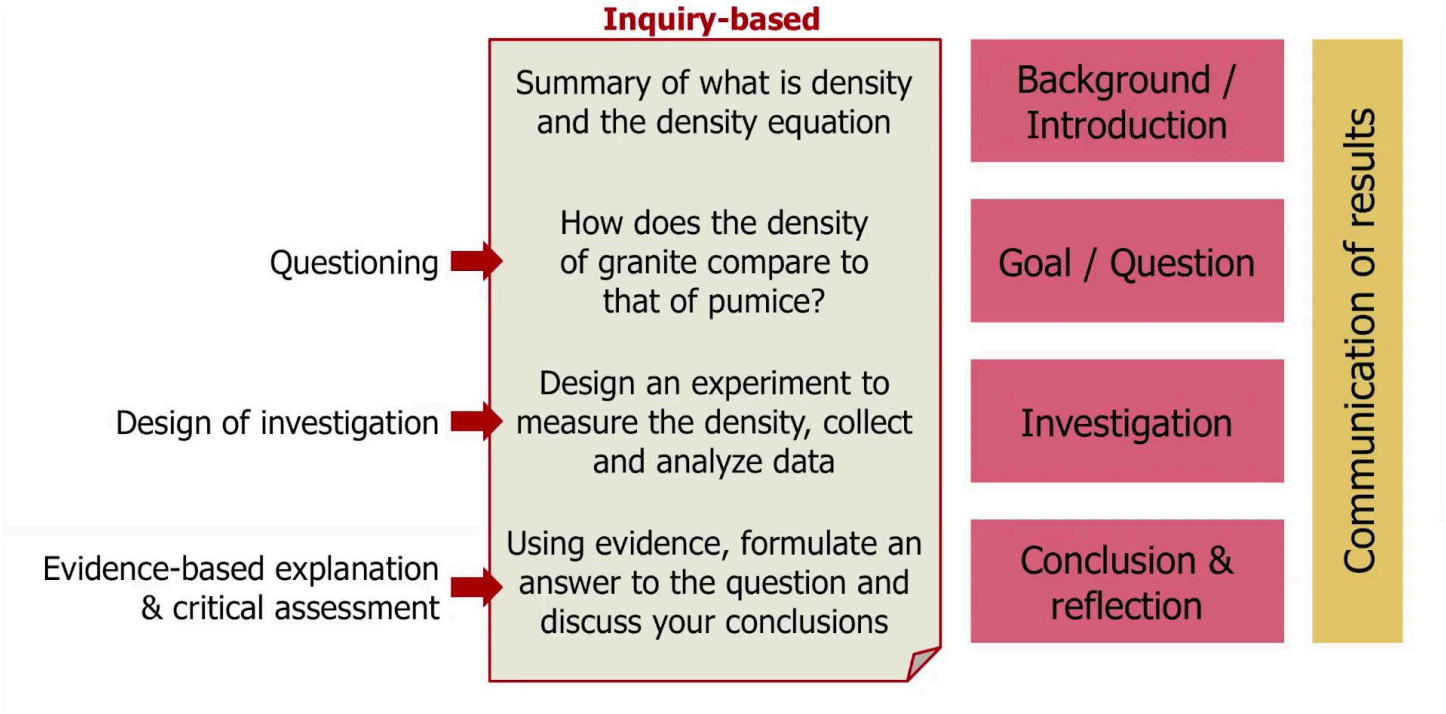
They could come up with various ideas such as to put the sample in water and to measure the amount of water it displaces for instance. From the data generated by their own experiment, they would then, be prompted to formulate an answer to the initial questions and more importantly to analyze the validity of their conclusions and therefore, to think about the limitations of their experiments. For instance what happens when you immerse pumice into water and how does that affect the result of the experiment? The communication aspect of the lab would still be to keep a lab notebook and to write a report just as in the verification lab. But the specific goal of communicating on an experiment in a way that allows others to reproduce it could be emphasized in an inquiry-based lab, specifically because different groups of students may implement different types of investigations.

Notes

Summary

9m 58s

What do inquiry-based labs look like?



So let's summarize the different key features of inquiry-based labs. First, they start with a question about the world for which students don't have a ready answer and that they need to decompose into a range of sub-questions, thus actively engaging in the details of the contact matter. Then students get the opportunity to design a scientific investigation, which requires them to think about what are the hypotheses, how to test them, what are the dependent and independent variables etc. etc. And finally students have to produce explanations based on evidence and use their critical thinking skills to assess them.

Notes

Summary

10m 59s

What do inquiry-based labs look like?

Inquiry-Based Lab
=
Use inquiry to find out about the world in a scientific way

Background / Introduction

Goal / Question

Investigation

Conclusion & reflection

Communication of results

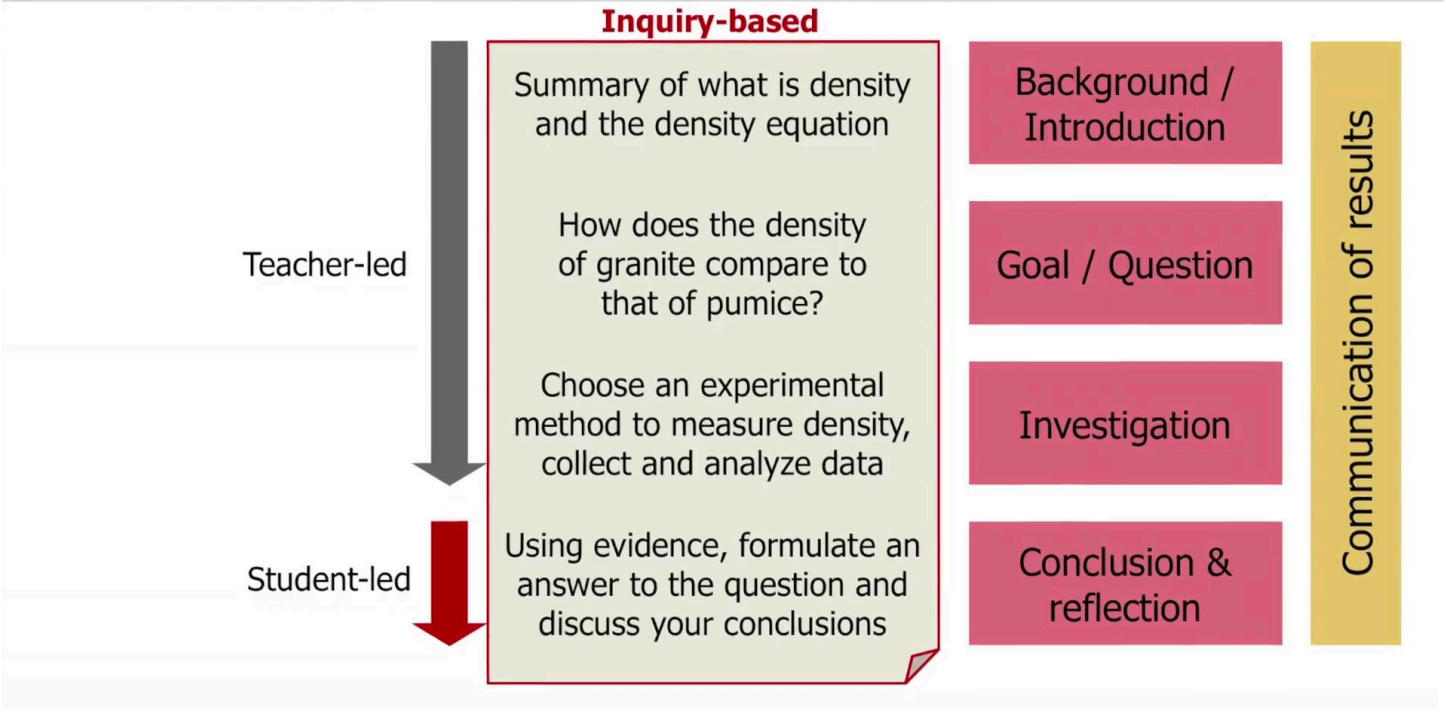
In brief, the principle of inquiry-based labs is for students to use inquiry to find out about the world in a scientific way. Now depending on the level of students, this might seem very ambitious or even a bit frightening but actually there can be varying degrees of direction from the teacher or from the teaching assistants in each of those steps.

Notes

Summary

11m 44s

Who is responsible for doing what?

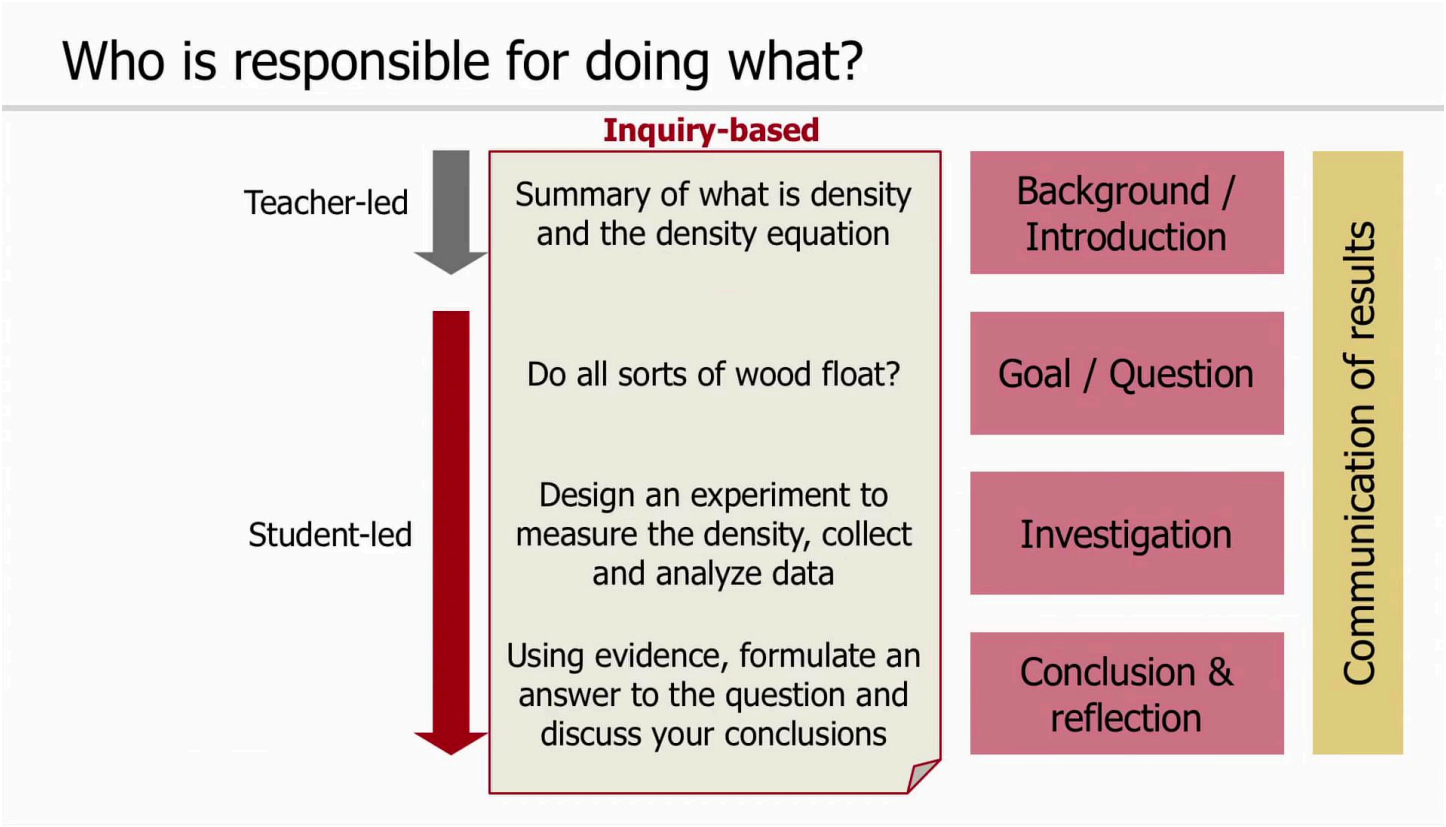


If we take a closer look at this example lab on density, the two first steps have actually been designed by the teacher. It is the teacher who has chosen which information to provide on the topic of the lab and it is the teacher who has chosen the question to address in the lab.Then the students have the responsibility to design and conduct the investigations and then to draw conclusions. If it is the first time students are exposed to the principles of scientific inquiry, more scaffolding can be necessary to accompany a bit more, the students in the development of their inquiry skills. So, for instance the teacher could provide information on the different types of experimental designs that schools could use to measure density and give them the choice of the experiment they want to implement. Students will still have then to collect data and to draw conclusion based on evidence.

Notes

Summary

12m 09s



At the other end of the spectrum, if students already have experience in designing scientific investigations, an interesting challenge for them could be to generate questions about density by themselves. So, for instance some students could be interested in knowing if all sorts of wood floats or not. And some others could want to know how a Galilean Thermometer works and therefore study the density of liquids. A key message here is that the level of direction in inquiry-based labs can be adjusted, depending on the level of students. Labs in the first years of bachelor could be more teacher-led, whereas labs in the last years of master could be more student-led, for instance.

Notes

Summary

13m 07s

Does it work?

Inquiry-based teaching:

- Results in better learning compared to other forms of instruction such as direct instruction or unassisted discovery
  (Alfieri et al., 2011 – 56 studies, $d = 0.30$, $p < .001$)
- Has a positive effect compared to traditional teaching, with higher impact when active guidance is provided to structure the activities
  (Furtak et al. 2012 – 37 studies, effect size of 0.50)
- Benefits to all students (Walker et al. 2016)

The effect of inquiry-based teaching on learning has been explored in a vast range of studies in the last decades. In 2011, Alfieri and her colleagues have published a meta-analysis comparing inquiry-based teaching with other forms of instruction, such as direct instruction and unassisted discovery. The analysis of 56 different studies shows that overall inquiry-based teaching results in increased learning compared to the other forms of instruction. The effect size that they found was small but meaningful. In another meta-analysis, Furtak and her colleague have focused on the extent to which activities are led by the teacher or by the students in inquiry-based teaching. Again they found that inquiry based has a positive effect compared to the traditional teaching. In addition, their results suggests the importance of the whole of the teacher in actively guiding students' activities. In particular, they show that inquiry-based teaching has a higher impact when guidance and scaffolding are provided to assess learners. Finally, it is important to underline that specific studies on inquiry-based teaching have shown that it benefits to all students including female students, underrepresented minority students, and students with lower past academic achievements.

Notes

Summary

13m 56s

The key: "doing with understanding"

Learning-by-doing is efficient **if students are driven to reflect on what they learn**

(Barron et al., 1998)

Background / Introduction

& reflection

Goal / Question

& reflection

Investigation

& reflection

Conclusion & **reflection**

Communication of results

& reflection

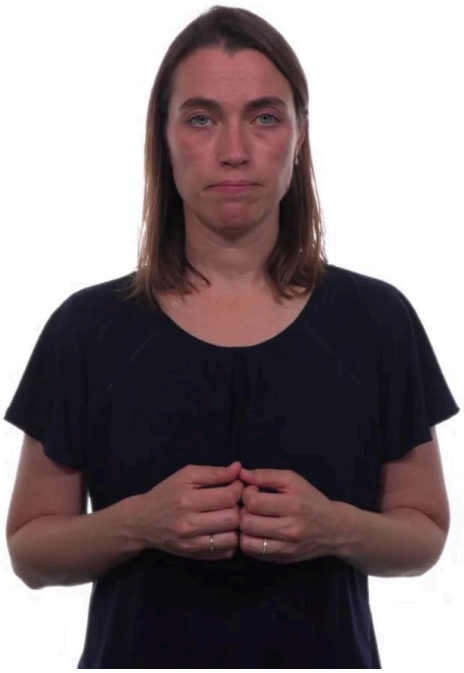
A key to the positive impact that inquiry- based teaching has on student learning is reflection. As Barron and her colleagues from Vanderbilt University underline, learning by doing should lead to doing with understanding rather than doing for the sake of doing. Reflection should actually not be limited to the conclusion of the lab but instead embedded into all the lab steps. This is why supporting students in reflecting on what they learn is one of the key roles that teaching assistants have when supervising labs.

Notes

Summary

15m 27s

Summary



Inquiry-based labs:

- Engage students in the **scientific inquiry process**
- Have a higher impact when **guided**
- Should drive students to **reflect** on what they learn

Let’s summarize what we have seen so far. After discussing the learning objectives of labs, we have introduced the idea of inquiry- 193 00:16:12,980 --> 00:16:18,999 based labs as a way to engage students in the scientific inquiry process. We have discussed the impact of inquiry-based teaching on learning and in particular the importance of guidance to scaffold student learning during labs. Finally we have introduced the idea that, to learn from doing, students need to be driven to reflect during all the stages of the inquiry process.

Notes

Summary

16m 04s

Special thanks to...

- Siara Isaac
  EPFL, Teaching Support Center
- Scott Auerbach
  UMass, Chemistry Department

I would like to say a special thank you to two persons for the help in preparing this video, Siara Isaac, my colleague from the teaching Support Centre at EPFL who has developed many of the resources on which this video is based and Scott Aurebach, professor in chemistry at the University of Massachusetts for his insights on inquiry-based and design- based learning.

Notes

Summary

16m 40s