Teaching the Skills of Professional Astronomy through Collaborative Introductory Labs

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Introductory Astrophysics

- ASTR120 & ASTR121 (with lab).
  - Two-semester sequence for science majors.
- Students taking the lab should:
  1. Experience astronomy through practical exercises.
  2. Develop skills needed for professional astronomy, e.g., collaboration, data analysis, critical thinking.

Transforming the Lab

1. Focus on fundamental topics (6 labs, not 10).
2. Think about the approach (freedom to explore).
3. Connect to current research (prelab reading).
4. Write comprehensive reports (formal sections).
5. Collaborate & critique (group work).

1. Focus on Fundamental Topics

- Just six labs:
  1. Intro to MATLAB.
  2. Stellar Parallax.
  3. Blackbody and Stellar Spectra.
  4. Cluster H-R Diagrams.
  5. HI Rotation Curves.
  6. Hubble's Law.

Each lab spans *2 weeks* (4 hours in-lab time).

1 ugrad LA per section (20 students per LA).

2 sections.

ASTR 121 – Spring 2015

Lab 5 – HI Rotation Curve of the Milky Way

Important dates:

- Prelab due: Monday, April 13, 2015
- Rough draft due: Monday, April 20, 2015
- Final draft due: Friday, April 24, 2015

Science Goals:

At the end of this lab, you should be able to…

- Determine the tangent velocity of HI clouds using 21 cm data
- Determine the orbital speed and orbital radius of the clouds via the tangent point method
- Construct a rotation curve of the galaxy based on these measurements

MATLAB Goals:

In this lab, you will apply MATLAB knowledge to…

- Plot data with x and y error bars
- Fit experimental data and determine information from a fit

2. Think About the Approach

- Lab manual gives broad instructions. It's not a cookbook.

"For each pair of images, you will determine the plate scale *s* and the apparent separation *a* of a star between the two images."

- Questions provide students opportunities to reflect on their work.

"What real systems can be represented by each of these rotation curves?"

3. Connect to Current Research

- Required pre-lab assignment to read a related "astrobites" article and answer a few questions.
  - http://astrobites.org/

astrobites

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Mapping the Milky Way

by Caroline Huang | Jul 3, 2015 | Daily paper summaries | 0 comments

Title: The Skeleton of the Milky Way

Authors: Catherine Zucker, Cara Battersby, and Alyssa Goodman

First Author's Institution: Astronomy Department, University of Virginia

Status: Submitted to the *Astrophysical Journal*

How many spiral arms does the Milky Way have? You might be surprised to learn that astronomers are still not completely sure. Unlike other galaxies that we can see face-on, our location in the Milky Way makes it hard for us to determine the structure of our own home galaxy.

CO and the Milky Way

Figure 1: The velocity-integrated map of CO, which traces out the distribution of H2 in the Milky Way. The color indicates the density of the molecular gas. From Dame, Hartmann, and Thaddeus (2001). To see a bigger image, check out this link: https://www.cfa.harvard.edu/mmw/Fig2_Dame.pdf)

A lot of what we do know about the Milky Way's structure comes from radial velocity measurements of interstellar gas and much of the interstellar gas is contained in giant molecular clouds (GMCs). Using the line-of-sight velocities of the gas and the Milky Way's rotation curve, we can determine the distances of the gas from the center of the Galaxy, mapping out the structure of the Milky Way. These molecular clouds consist mostly of molecular hydrogen, or H2. Because H2 lacks a permanent electric dipole moment, it is almost invisible at the low temperatures of the molecular clouds, making it very difficult to detect directly. Instead of measuring emission from molecular hydrogen to locate the GMCs, astronomers often use tracers for the molecular hydrogen, like CO. These tracers make up a small fraction of the gas in molecular clouds, but they have lower-frequency transitions that we can detect. By mapping out the emission of CO across the sky, we can also effectively map out the location of the giant molecular clouds. Figure 1 shows a velocity-integrated map of the Milky Way using CO as a tracer, from Dame, Hartmann, and Thaddeus (2001).

However, when piecing together the three-dimensional structure of the galaxy this way, it can

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4. Write Comprehensive Reports

- We use *faded scaffolding*:
  - Students provided with a template for each lab report, with some (mostly) filled-out sections.
  - Each new lab has fewer pre-filled report sections.
  - The last lab report has no pre-filled sections at all.
- Graded using a detailed rubric.

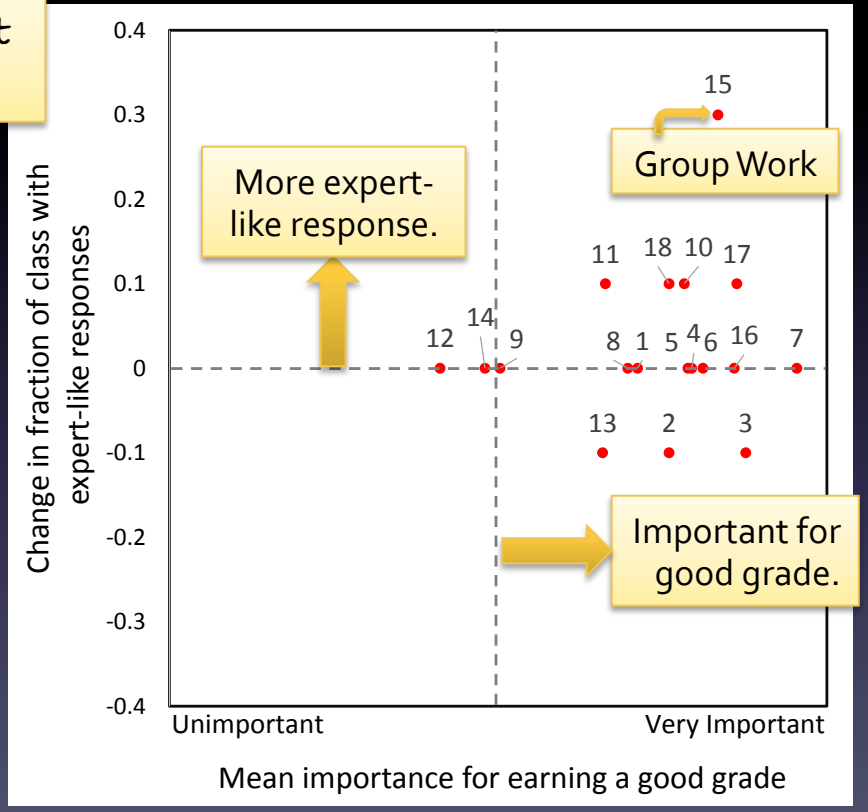
5. Collaborate & Critique

- Students work in pairs.
- Whole class encouraged to cooperate.
- At the start of the second week of each lab, pairs exchange draft lab reports for comment.

Evaluating Our Success

15. "Working in a group is an important part of doing astronomy experiments."

- Modified E-CLASS survey (Zwickl+13) shows students' expectations of what is important to experts are aligned with assessments.



Summary

- We have transformed the UMD ASTR121 lab to make it more collaborative and relevant for students.
- Student views on astronomy labs became more expert-like.
- Will continue to refine the improvements this year (spring 2016).
- Materials available online (plus teaching manual): ter.ps/9jm
- We thank the UMD TLTC Elevate program for support.
- Related poster: PST2A07 (yesterday, sorry!).

Extra Slides

Excerpt from Lab 4
(Cluster H-R Diagrams)

Part 1: Examining Star Cluster Data and Exploring Photometric Filters

In this part of the lab, you will examine the data for an open cluster.

1. In a MATLAB script, read in the data for the open cluster M41. Create a CMD by plotting V apparent magnitude as a function of (B-V), remembering to flip axes as needed. As this is a set of individual points representing distinct stars, have the figure plot points rather than connecting them in a line. Add appropriate axes and title, and include this figure in your report. *Which direction does temperature increase on the x-axis? What features can you identify on this CMD?*

2. On your CMD, look for a main sequence star with (B-V) of 0.5. *What surface temperature would this star have?* Using your Planck function from the previous lab, plot the blackbody curve of an object with this temperature. Include this figure in your report.

3. The data includes apparent magnitudes in the B and V filters. Show on your blackbody plot which wavelength range each filter allows through, as well as the central wavelength of each filter. Include this figure in your lab report.

Excerpt from Lab 5
(HI Rotation Curves)

Part 1: Exploring Rotation Curves

In this part of the lab, you will construct rotation curves for different mass distributions. You will use the equation for orbital speed v around an enclosed mass M_r at an orbital radius r,

$$v = \sqrt{\frac{GM_r}{r}},$$

where G is the gravitational constant.

1. Consider a system in which almost all the mass is concentrated in a point at the center, resulting in a constant value of M_r. Construct a rotation curve for this system by plotting orbital speed as a function of orbital radius. To set a reasonable scale, use a value of M_r equal to the total mass of the Milky Way and take r to vary on kiloparsec scales.

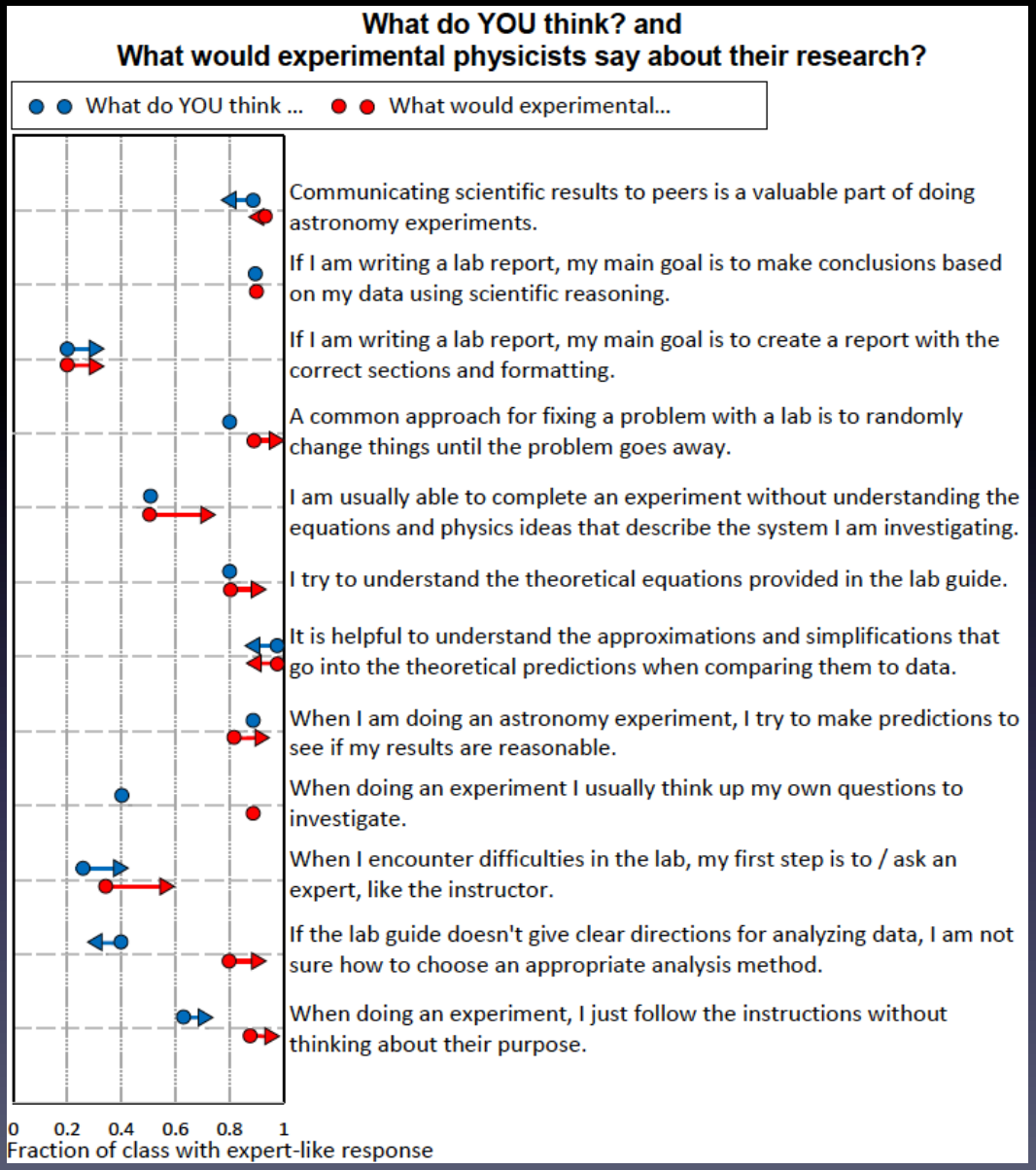
2. Plot a similar curve for a system where enclosed mass is proportional to orbital radius, $M_r \propto r$. Use similar scales as for the previous model and show them together.

3. Add a third plot showing a distribution where enclosed mass is proportional to volume, $M_r \propto r^3$. *What real systems can be represented by each of these rotation curves?*

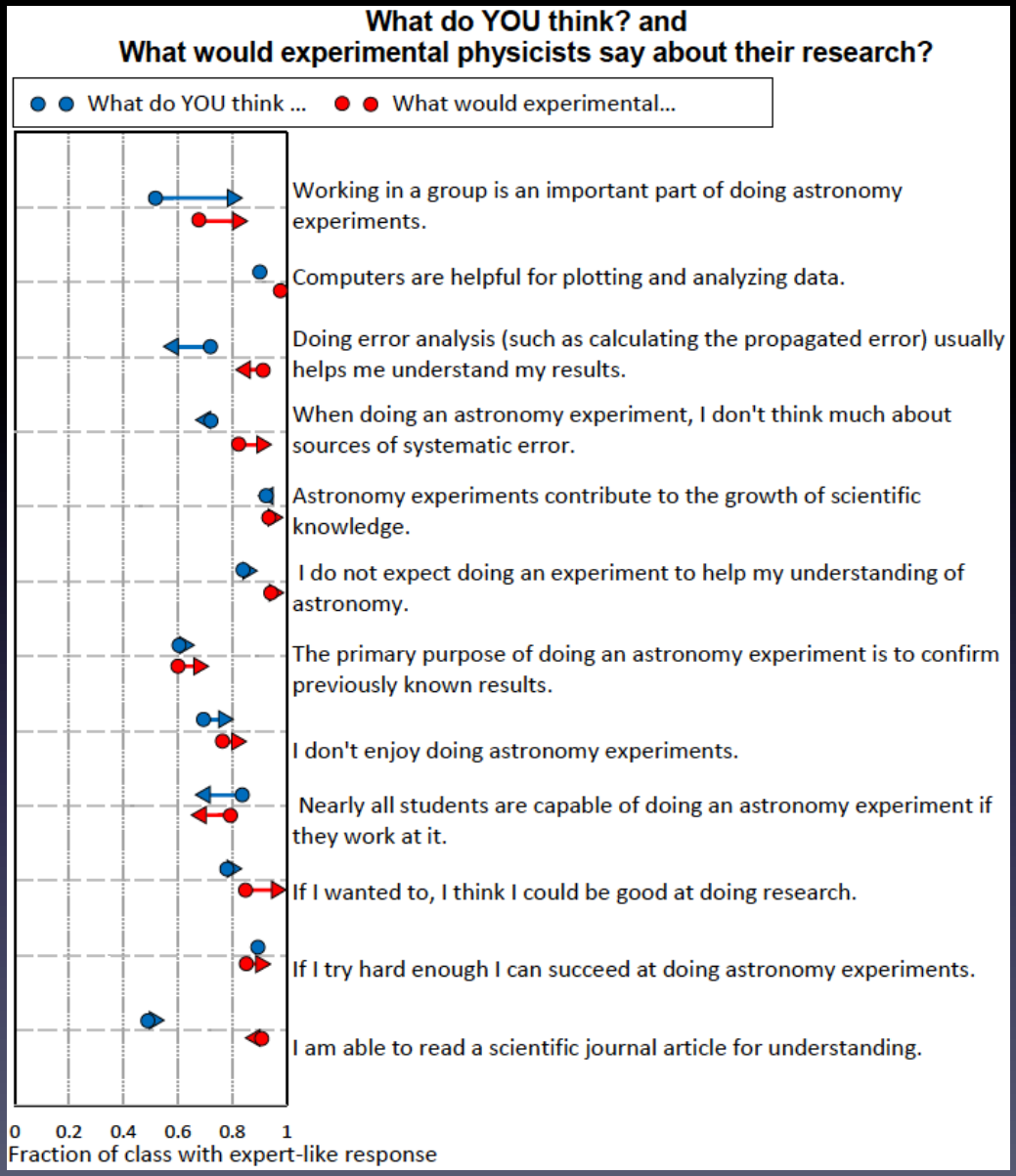
ASTR121 Lab Report Rubric – 38 Points Total

Aspect	**Excellent** (100%)	**Good** (75%)	**Adequate** (50%)	**Poor** (25%)	**Absent** (0%)
Cover Page (2 pts)	Cleary presents name and number of lab, student names and contact information, date, course and section	Missing an aspect	Missing aspects	Missing all aspects	Absent
Abstract (4 pts)	Concisely summarizes the purpose, procedures used, and results of project.	Missing an aspect	Missing aspects; too lengthy or inaccurate	Missing all aspects	Absent
Introduction (4 pts)	• Includes the question to be answered by the project • Develops the reason why the question is relevant/interesting • Discusses general method (without specifics) that will be used to answer the question and develops theoretical background	One is missing	Two are missing	Three are missing	Absent
Methodology (8 pts)	Description of the data used and what was done with the data, complete enough that another scientist could repeat the process.	Some steps are vague or unclear	Only includes generalities, but enough to get the idea	Would be difficult to repeat; reader must guess at some parts	Absent
Analysis (8 pts)	Results and data are clearly displayed, organized in a way that makes it easy to see trends. Figures and charts are appropriately labeled and captioned. Excessive data and Matlab code are included in appendix. Uncertainties in all determined quantities are calculated and explained.	Errors in results, but otherwise well done; flaws in organization	Unclear results; missing labels or captions; disorganized; missing data/plots/tables	Results do not make sense, or not enough to justify conclusions	Absent
Discussion (8pts)	• Summarizes the data used to draw conclusions • Conclusions follow logically from data • Discusses sources of error (random and systematic) • Discusses if conclusions fit expectations and/or seem plausible • Discusses any unusual results or disagreement with theory and speculates on cause • Discusses addition questions/issues asked in hand-out • Discusses real world implication of results	Missing 1-2 aspects	Missing 3-5 aspects	Missing 5-6 aspects	Absent
Format (4 pts)	• Report follows typical scientific format and organization • Any references are cited appropriately in a bibliography • Writing flows well and is easy to read • Grammar, vocabulary, and similar errors are minimized	Some grammar, writing, or formatting issues.	Significant errors in one aspect, minor errors otherwise	Significant errors in many aspects	Paper is nearly unreadable

Modified E-CLASS Survey Results (Part 1)



Modified E-CLASS Survey Results (Part 2)



Modified E-CLASS Survey Question Key

Number	Personal/Professional Statement	How important for earning a good grade in this class was…
1	When doing an astronomy experiment, I don't think much about sources of systematic error.	…thinking about sources of systematic error?
2	It is helpful to understand the assumptions that go into the theoretical predictions when comparing them to data.	…understanding the approximations and simplifications that are included in theoretical predictions?
3	Doing error analysis (such as calculating the propagated error) usually helps me understand my results.	...calculating uncertainties to better understand my results?
4	If I don't have clear directions for analyzing data, I am not sure how to choose an appropriate analysis method.	…choosing an appropriate method for analyzing data (without explicit direction)?
5	I am usually able to complete an experiment without understanding the equations and physics ideas that describe the system I am investigating.	…understanding the equations and physics ideas that describe the system I am investigating?
6	I try to understand the theoretical equations provided in the lab guide.	…understanding the relevant equations?
7	Computers are helpful for plotting and analyzing data.	…using a computer for plotting and analyzing data?
8	When I am doing an astronomy experiment, I try to make predictions to see if my results are reasonable.	…making predictions to see if my results are reasonable?
9	When doing an experiment I usually think up my own questions to investigate.	…thinking up my own questions to investigate?
10	When doing an experiment, I just follow the instructions without thinking about their purpose.	…thinking about the purpose of the instructions in the lab guide?
11	When I encounter difficulties in the lab, my first step is to ask an expert, like the instructor.	…overcoming difficulties without the instructor's help?
12	A common approach for fixing a problem with a lab is to randomly change things until the problem goes away.	…randomly changing things to fix a problem with the experiment?
13	Communicating scientific results to peers is a valuable part of doing astronomy experiments	…communicating scientific results to peers?
14	I am able to read a scientific journal article for understanding.	…reading scientific journal articles?
15	Working in a group is an important part of doing astronomy experiments.	…working in a group?
16	If I am writing a lab report, my main goal is to make conclusions based on my data using scientific reasoning.	…making conclusions based on data using scientific reasoning?
17	If I am writing a lab report, my main goal is to create a report with the correct sections and formatting.	…communicating results with the correct sections and formatting?
18	The primary purpose of doing an astronomy experiment is to confirm previously known results.	…confirming previously known results?

Lab Facility

- 10 PCs for 40 students in 2 sections.
- Students work in pairs.

Classroom

Capacity 50 students.

Pretty crowded!