Teaching the Skills of Professional Astronomy through Collaborative Introductory Labs

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University of Maryland, College Park
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.
  5. HI Rotation Curves.

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.
- Questions provide students opportunities to reflect on their work.

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

“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.
  
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.

More expert-like response.

Group Work

Important for good grade.
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!).
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.
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

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

What do YOU think? and
What would experimental physicists say about their research?

- Communicating scientific results to peers is a valuable part of doing astronomy experiments.
- If I am writing a lab report, my main goal is to make conclusions based on my data using scientific reasoning.
- If I am writing a lab report, my main goal is to create a report with the correct sections and formatting.
- A common approach for fixing a problem with a lab is to randomly change things until the problem goes away.
- I am usually able to complete an experiment without understanding the equations and physics ideas that describe the system I am investigating.
- I try to understand the theoretical equations provided in the lab guide.
- It is helpful to understand the approximations and simplifications that go into the theoretical predictions when comparing them to data.
- When I am doing an astronomy experiment, I try to make predictions to see if my results are reasonable.
- When doing an experiment I usually think up my own questions to investigate.
- When I encounter difficulties in the lab, my first step is to ask an expert, like the instructor.
- If the lab guide doesn't give clear directions for analyzing data, I am not sure how to choose an appropriate analysis method.
- When doing an experiment, I just follow the instructions without thinking about their purpose.
Modified E-CLASS Survey Results (Part 2)

What do YOU think? and
What would experimental physicists say about their research?

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

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

Capacity 50 students.

Pretty crowded!