How to use this guide

- This guide is divided into Three Sections. **Section One** is a quick startup guide, followed by **Section Two** on pre-lab, lab, and post-lab activities. Finally **Section Three** has more details about lab reports.

- For students, this guide presents information about how lab work is assessed and graded. This covers: the type of feedback you can expect and what to do with it, how to use the grading rubric, an example outline for a lab report, illustrative examples from actual student lab reports, and how scientific work falls under the same guidelines that are used in the general chemistry lab program.

- For instructors, this guide represents a summary of the guidelines recommended for use across the general chemistry lab program. All lab instructors take a graduate level course that covers these guidelines and integrates a range of activities into their professional practice including how lab work should be conceptualized, giving students feedback, and different ways that learning outcomes can be assessed.
Section 1: Quick Startup Guide
Useful Stuff

- If you need to make up a lab, you should consult the FAQ (frequently asked questions) list on the general chemistry website: http://umaine.edu/general-chemistry/faq/

- The address for InterChemNet is http://icn2.umeche.maine.edu/newnav/NewNavigator/LoginForm.cfm
Quick Startup Guide

- Lab experiments are selected online using your InterChemNet account where you will be able to download the lab procedures.

- You can find the InterChemNet login page by doing a Google search on “InterChemNet” or by going to http://icn2.umeche.maine.edu/newnav/NewNavigator/LoginForm.cfm.

- In order to log into InterChemNet, you need to have an access packet containing a code number which is purchased at the University of Maine bookstore (this is the only place to purchase these and the code number is found in the packet and can be used for one lab course).

- There is an accompanying general chemistry website (http://umaine.edu/general-chemistry/) which contains both lecture and lab information including answers to many common questions (http://www.umaine.edu/general-chemistry/faq/).
Lab Grades for Each Experiment

- Lab grades are assigned for each experiment considering these factors:
  1. 10%: pre-lab assignment and pre-lab discussion.
  2. 10%: safe behavior in lab.
  3. 10%: laboratory work including taking notes.
  4. 10%: post-lab discussion.
  5. 60%: Laboratory Report.

- Lab reports are graded on a 0-60 pt scale and will be posted on your InterChemNet page. Pre-lab assignments are graded and returned. The remaining points (safety, lab work, post-lab) are presumed, and a lab instructor will inform students only if they do not earn full credit. Deducted points are communicated by the time lab reports are returned. Typically students lose points when they do not attend pre- or post-lab discussions, do something unsafe in lab, or do not use their lab notebooks properly.
Lab Report Rubric*

The lab report rubric is a conceptual framework to identify the required components in each lab report. For each component, the rubric describes the type of work that would fall into level 0 (poor), 1 (average), and 2 (excellent) work. Section three illustrates the application of the rubric in more detail.

Please note: there are essential features that are expected (and assumed) for every lab report. Essential features include: Title of Experiment, Name, Introduction, and Explanation of lab procedures. Points will be deducted when these features are missing; typical deductions: missing title: -5 pts; missing name -5 pts; missing introduction: -5 pts; missing procedures section: -5 pts.

<table>
<thead>
<tr>
<th>Lab Report Rubric</th>
<th>Level of attainment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Required Components</strong></td>
<td><strong>Level 0 (0-20 points)</strong></td>
</tr>
<tr>
<td><strong>Claim(s):</strong> Is a statement(s), derived from evidence, using scientific reasoning. The claim should be underlined on the first page following the introduction.</td>
<td>Does not make a claim, or makes an inaccurate claim.</td>
</tr>
<tr>
<td><strong>Evidence:</strong> Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.</td>
<td>Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support claim).</td>
</tr>
<tr>
<td><strong>Reasoning:</strong> Scientific arguments that use evidence and appropriate scientific principles to make claims.</td>
<td>Does not provide reasoning, or only provides reasoning that does not link evidence to claim.</td>
</tr>
</tbody>
</table>

*Rubric inspired by the work of Dr. Joseph Krajcik, et al.*
Section 2: pre-lab, lab, and post-lab activities
40% of the lab grade is assigned for activities that happen before and during lab:

1. 10%: prelab assignment and prelab discussion.

2. 10%: safe behavior in lab.

3. 10%: laboratory work including taking notes.

4. 10%: post lab discussion.
Pre-lab Assignment and Prelab Discussion (10%)

☐ The pre-lab assignment is handed in at the beginning of the lab period. The pre-lab assignment contains questions about the upcoming lab including a section on safety. The pre-lab assignment is graded and worth 5%. Without it, you can not begin lab.

☐ Participation in the pre-lab discussion is required. Your presence will earn you 5%. During the pre-lab discussion, the lab instructor will relate important lab information, review the pre-lab assignment, discuss the upcoming lab, and give you an opportunity to ask questions. If you arrive late, the 5% cannot be recovered.
Safe behavior in lab (10%)

- No work can take place in lab without understanding how to conduct the experiments safely.

- You are required to attend a safety presentation at the beginning of the semester and successfully pass a safety quiz in order to continue in the lab course.

- Safety is everyone’s concern. If you ever see anything unsafe going on in lab please report this to your lab instructor. If you are unsure if you are doing something safely, please do not proceed without consulting your lab instructor.

- The pre lab will include safety information. If you haven’t completed the safety section, you will not be allowed to start lab.

- Safe behavior is presumed and 10% is earned for each lab. If a student exhibits unsafe behavior, the lab instructor has the responsibility to ask students to correct the behavior and even to leave lab. If this occurs, before being allowed to reenter lab, the incident will need to be reviewed by the general chemistry coordinator and laboratory manager.
To a large extent, you control what you do in lab. Successful lab work takes active planning and thinking.

What you do in lab is a reflection of the care and attention given to your laboratory work.

Sometimes there is room for creative and critical thinking in lab work. For example, the lab procedures are, by design, sometimes incomplete. You may be asked to design an experiment to test a hypothesis. You may be able to design the experiment in more than one equally valid way. Scientists sometimes follow different methods to accomplish the same task and this has led to important scientific discoveries.

You should use the lab notebook to describe how you approach tasks, answer questions posed in the lab procedure, make observations, and to record important information like the mass of a chemical. Trying to save pages in a lab notebook for next semester is a “penny wise - pound foolish” way of using your lab notebook.

Lab instructors assign 10% of your grade from lab work. It is rather easy to earn the 10%. It is not so easy, however, to use your time in lab carefully and thoughtfully.
Post-Lab Discussion (10%)

- By the end of lab, you will have gathered evidence. The post-lab discussion is about the process of thinking about this evidence and how it can be analyzed, through reasoning, to make valid scientific claims.

- Not all of the evidence you will gather will be easy to interpret. For example, sometimes mistakes in lab will make conclusions very difficult. However, there is no requirement to get a certain outcome in your lab work. What is required is that you work with the evidence you have generated (unless told by a lab instructor to do otherwise). The post-lab discussion can make writing up your results easier.

- Timing of the post lab discussion varies. Your lab instructor will appreciate your help in forming a group of 4-8 students to have a post lab discussion. Students can have this discussion without the lab instructor but touching base with the lab instructor should always occur before leaving lab.

- To document the post-lab discussion, you should write 5-6 summarizing sentences in your lab notebook, under the heading, Post-lab Discussion.

- The post-lab discussion carries 10 pts for participation. If your lab instructor notices that you do not participate in the lab discussion and that you do not write the summary, these points will not be awarded.
Section 3: lab reports
Lab Report Basics

- During the first few weeks of the semester, your lab report will receive a Tentative Grade from the instructor, which can be improved if resubmitted, taking into account lab report deficiencies. Please see section A on Lab Report Tentative Grade and Regrades as well as section B on: What Can I Expect and What Do I Do with Lab Instructor Feedback?

- Sections C-E look at each of the three components in the rubric separately that were first presented in the Quick Startup Guide (Section 1).

- A suggested outline for a lab report is shown in section F, illustrating each of the components of the rubric.

- Sections G, H, and I contain lab report details including information from actual student lab reports.

- Finally, in section J, a recent scientific publication is shown - illustrating how claim, evidence, and reasoning are used in a scientific paper.
Section A: Lab Report Tentative Grade and Regrades

- During the first few weeks of the semester, your lab report will receive a tentative grade from the instructor. This grade can be improved if resubmitted, taking into account lab report deficiencies. This applies to the first two lab reports.

- In these first two lab report regrades, you can earn all of the points back.

- After that, your TA may ask you to revise a lab report. If this occurs, the maximum score you can achieve on the regrade will be one half of the difference between the maximum and the grade you received.

In the first two lab reports, you can earn all of your points back on a regrade.
**Section B: What Can I Expect and What Do I Do with Lab Instructor Feedback?**

- This section is part of a “living” document that will be continually added to over time. Our initial examples are shown on this page.

<table>
<thead>
<tr>
<th>Example</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>We determined the calorimeter's heat capacity to be 1.88 unit?</td>
<td>The units are missing. There are two important aspects about correcting this in a lab report. First, you need to make the correction. Second, you need to carefully review the lab report for all such occurrences.</td>
</tr>
<tr>
<td>Show work!</td>
<td>Units are part of evidence, which in total is worth 20 points. A single occurrence of a missing unit may be marked down “-1” with multiple occurrences up to “-6” points!</td>
</tr>
<tr>
<td>What was your unknown Concentration? How did you determine this?</td>
<td>A result was shown without any information about how the result was arrived at. This is common for a result based on a calculation. The lab report should document this process.</td>
</tr>
<tr>
<td>This student earned a failing grade on the lab report. Each item should have been supplied.</td>
<td></td>
</tr>
<tr>
<td>Missing: Your spectra! -10</td>
<td>A major item was missing from the lab report. This would result in a major mark down. The remedy is to supply this information. Be careful to show work.</td>
</tr>
<tr>
<td>Graph Abs vs. concentration for Nickel -5</td>
<td>Omitting a major section results in a large deduction.</td>
</tr>
<tr>
<td>Use graph to find conc. of unknown -3</td>
<td>The lab instructor has identified a list of items (longer than shown). This student did not understand what was required for a complete lab report.</td>
</tr>
<tr>
<td>Sketch of instrument -2</td>
<td>This student earned a failing grade on the lab report. Each item should have been supplied.</td>
</tr>
</tbody>
</table>
## Section C: Lab Report Evidence

<table>
<thead>
<tr>
<th>Lab Report Rubric</th>
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<td><strong>Component</strong></td>
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<tr>
<td>Evidence: Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.</td>
<td>Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support claim).</td>
</tr>
</tbody>
</table>

- The scientific evidence you gather in lab are facts and information that helps support claims.
- For example, if you measured the boiling point of water with a thermometer, and you found that water boiled at 99.8 °C, 100.1 °C, and 99.9 °C, you might use that to indicate that the water in your experiment boiled at an average temperature of 99.9 °C. The three measurements are evidence. But you also add to your evidence observations that gas bubbles were generated at the boiling point.
- You can also cite a reference source (e.g. textbook), that water boils at 100 °C at 1 atm. pressure and approximately 95 °C in Denver, CO where the air pressure is lower.
## Section D: Lab Report Reasoning

<table>
<thead>
<tr>
<th>Lab Report</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Component</strong></td>
<td>Level 0 (0-20 points)</td>
</tr>
<tr>
<td>Reasoning: A justification that links the claim and evidence. It shows why the data counts as evidence by using appropriate and sufficient scientific principles.</td>
<td>Does not provide reasoning, or only provides reasoning that does not link evidence to claim.</td>
</tr>
</tbody>
</table>

- Scientific reasoning connects evidence and claims.
- If you measured the volume of a gas as a function of pressure and temperature, the evidence you generate can be tabulated and graphed. However, it is the interpretation of the evidence, that allows you to make claims.
- For example, let’s say that your evidence indicates that as temperature increases, the volume of the gas increases for a constant number of moles of gas and constant pressure. This evidence is turned into a claim by reasoning that there is a proportionality constant \( k \) between volume \( V \) and temperature \( T \) that can be written as \( V = kT \) (at constant number of moles of gas and constant pressure).
- An outside source might be brought into the reasoning such as referencing the ideal gas law, \( PV = nRT \). Recognizing that for a constant number of moles of gas and constant pressure, the equation can be re-written as \( V = (nR/P)T \), suggesting that the proportionality constant \( k \) is equal to \( nR/P \).
- Reasoning enriches the scientific discussions and by bringing in outside sources or studies, allows a much stronger connection to be established between evidence and claim.
You are given three bottles: two unknown white powders and one labeled “aspirin”. Each is white. To evaluate the substances, you measure the melting point and find: “aspirin”: mp=137 °C; unknown A: mp = 138 °C; unknown B: mp = 137 °C. You make the claim that all three substances are consistent with aspirin because melting point is a characteristic property of substances. However, you note that you consider your claim tentative and suggest it is weak because many compounds are white with the same melting points.

To strengthen your claim, you determine the mass and volume each substance and calculate the densities: “aspirin”, d = 1.4 g/mL; unknown A, d = 1.41 g/mL; unknown B, d = 1.39 g/mL. This new evidence supports your initial claim (within the error of your measurements); you have strengthened your original claim but the claim is still not strong since there may be different compounds having the same mp and d.

Finally, you take an infrared (IR) spectrum of each sample: they all have similar patterns of infrared peaks. You now consider your claim much stronger and state that the substances are very likely all samples of “aspirin”.

![infrared spectrum](Image of infrared spectrum)
Section F: Example Lab Report Outline

I. Title of Experiment, Name (partner names if applicable), date the experiment was conducted, lab section, and lab instructor.

II. Introduction: (typically 1-3 paragraphs, sometimes with equations and a figure). An introduction explains the lab, summarizing your results and states why the experiment was important.

YOUR CLAIM(S) SHOULD BE CLEARLY PRESENTED AND UNDERLINED FOLLOWING YOUR INTRODUCTION

III. Results: this section describes the evidence you have gathered during the experiment. This may include data (e.g. “the mass of a compound was ...”), observations (e.g. the solution turned blue after adding HCl”), calculations, graphs, and tables.

IV. Discussion: contains your reasoning for how you can build a scientific case connecting your results (evidence) to claims. In supporting your case you may build upon other sources of information, including textbooks and scientific papers.

V. Summary/Conclusion are optional but very useful in providing a condensed version of the lab report. Evidence can be highlighted, the discussion can be summarized, and the claims restated.
Section E: Lab Report Claims

<table>
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<tr>
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<tr>
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<td>Level 0 (0-20 points)</td>
</tr>
<tr>
<td>Goes not make a claim, or makes an inaccurate claim.</td>
<td>Makes an accurate but incomplete claim.</td>
</tr>
</tbody>
</table>

- A scientific claim builds a case based on evidence using sound reasoning. In contrast, a claim that lacks evidence is scientifically worthless and misleading.

- A claim is not proof in the sense that it has to be 100% correct to be useful or scientific. A claim is supported by the evidence and the reasoning constructs arguments to understand both the strengths and weaknesses of a claim.

- Your claim has to be placed prominently in the lab report so it can be identified as a claim and a person who is reading the lab report can see how the evidence and reasoning supports the claim.

- A discussion of claims is described on the next page.

- Remember that the claim should be included in the beginning of your lab report along with the introduction, safety information, and procedures.
Section G: A detailed look at the beginning of a lab report including where to make your claims (based on actual student work).

- At the beginning of the lab report, you are expected to include certain essential features such as Title of Experiment, Name, Introduction, Underlined claim on first page of lab report, and procedures. Points will be deducted ONLY when these features are missing.

- **Where to make your Claim.** Scientific papers typically convey claims in the **Title** and **Abstract**, placed at the very beginning of a paper. To evaluate the strength of claims, scientists look at the evidence and reasoning used to support the claim. Therefore, we should recognize that while the claims go at the beginning of your lab report, all of your claims should be based on the evidence and reasoning presented in other parts of the lab report. It makes sense then, that you would finalize your claims only after the other sections were written. Modern word processing programs make this easy to do!

- Looking over the grading rubric, you will see three major components: Claims, Evidence, and Reasoning. **Twenty points (out of 60 pts) are earned for the quality of your claim.** The lab instructor will look over the evidence (present in other parts of your lab) as well as your reasoning, and will judge if your claim is based on these other components. You are not judged on a result - but rather if your claim is logical and reasonable based on the data from lab as well as how you interpreted it (i.e. reasoning).

- In the red box below, is the beginning part of a lab report (Title omitted) including: Introduction, Claim, and Procedure sections. This is based on an actual student lab report from fall, 2011. Based on the evidence and reasoning (present in the other sections of the lab report), **this lab report earned 20 pts. for the claim.**

```
Introduction
This lab is an introduction to the use of a UV-vis spectrometer. Stated by the lab manual on InterChemNet: “A UV-vis spectrometer is an instrument used to measure the amount of ultraviolet and visible absorbed by a solution”. Solutions of different metal ions have different characteristic patterns of absorbance bands. The absorbance bands of a series of known metals ions were recorded using a UV-vis spectrometer and then compared to an unknown solution.

Claim
Our claim is that our assigned unknown sample was cobalt. This was based on a comparison of the UV-vis spectrum of our unknown sample to that of the UV-vis spectra of known metal ions.

Safety Precautions!!!
Copper (II) Nitrate, Nickel(II) Nitrate, Cobalt (II) Nitrate, and Iron (III) Nitrate are all strong oxidizers. In their pure form they may cause fires when in contact with other materials. Although in this lab they are in solution, that doesn’t mean that they should be taken less likely.

Procedures
The procedures were taken from the InterChemNet website, “Qualitative and Quantitative Use of the UV-vis Spectrometer”, accessed November 8, 2011. The following changes were made to the procedures during the experiment:
....
....
....
```

**Notes:**

1. The Introduction is short but conveys a clear and focused description of the lab experiment.

2. The claim is underlined at the beginning of the lab report. This makes it easy for the lab instructor to see what claim(s) was made in the report. In this example, the claim is followed by a description of the way that evidence is used to make the claim. The lab instructor who graded this lab found this very useful!

3. The safety information was summarized in an easy to understand format.

4. The lab procedure was referenced, the date that the lab was downloaded was noted, and only the changes made that differed from what was written in the lab procedure were noted. These were explicitly and clearly described and taken directly from the lab notebook.
Section H: A detailed look at evidence presented in lab reports.

Looking over the grading rubric, you will see three major components: Claims, Evidence, and Reasoning. Twenty points (out of 60 pts) are earned for the presentation of evidence gathered in lab.

There are many different forms of evidence that can be included.

Data Tables are useful in presenting information. This example was taken from an actual lab report from fall, 2010. (Please note that 2 pts were deducted because the units for temperature were missing).

Figures are often required as part of the lab report. This example was taken from an actual lab report from fall, 2010. Here a student reproduced a drawing made from his/her lab notebook. This is perfectly acceptable, if the figure meets all of the requirements. Note that this figure includes units for the X (second) and Y (temp, °C) axes.
InterChemNet provides a UV-vis Beer’s Law subroutine for analyzing UV-vis data. The data taken from a fall, 2010 lab report shows student evidence including UV-vis spectra, a Table of absorbance (600 nm) and concentrations, and a plot of absorbance vs. concentration. A linear line (correlation coefficient = 0.99) is also determined which can be used as a standard calibration curve.

The selection of data, how many UV-vis spectra, input of the concentrations (found by using other data from the lab) are all key parts of the evidence presented in this page of a lab report. This student earned full marks for the evidence presented in this lab report (some of which is not shown here).
One aspect of evidence that is highly valued is evidence from other published sources that adds significance to gathered evidence (see grading rubric). The example here is from a student lab report called, FTIR Analysis of Greenhouse Gases (fall 2010) showing the FTIR spectrum of carbon dioxide. Note that the source of the figure was identified (a website). Please note that you should include an access date for any evidence taken from the Internet.
Section I: A Detailed Look at the Reasoning Section

Looking over the grading rubric, you will see three major components: Claims, Evidence, and Reasoning. Twenty points (out of 60 pts) are earned for the presentation of reasoning gathered in lab.

Reasoning involves constructing scientific arguments that use evidence and appropriate scientific principles to make claims.

Experimental data presents a number of challenges. To name a few: error, inappropriate procedures for the concept under investigation, missing data, and unclear logic used in reasoning. Applying reasoning to data can be tricky and requires very careful thinking. The reasoning is also often tied to the goals for a particular lab. If experiments are conducted using student designs, the goals of the experiments are also important to define and reason through in the lab report.

The reasoning section of a lab report is therefore, the hardest to define as well as illustrate. The example to the right is from a student lab report called “Identifying Metal Ions by Chromatography” from Fall, 2011. Some general discussion points are outlined below.

In the chromatography lab, four known metal ions were used to spot a strip of paper, and the ends placed in a solvent. By capillary action, the solvent moves up the paper, bringing with it to different extents, the metal ions. The distance the solvent moves (solvent front) as well as the distance each of the metal ions travels is measured and tabulated (i.e. evidence). The ratio is found to be characteristic of the metal ion (i.e. Rf value). Reasoning suggests that given similar conditions, an unknown metal ion will travel up the paper in such a way that the Rf can be used to identify the unknown metal ion solution. The student’s unknown can be run at the same time along side several known metal ions. The known metal ions are run in order to make sure that the conditions under which the unknown is run is similar to that when the known metal ions were previously run (and the Rf values calculated). The identity of the unknown is made based on the Rf value for known metal ions. The claim that the unknown was (e.g. cobalt) was then made. The colors of the solutions (qualitative data) can also be used as important indicators.

Table for Step 3

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Distance from Line to Leading Edge of Spot</th>
<th>Distance from Line to Solvent Front</th>
<th>Rf value</th>
<th>Color of the observable spots during and after each step in the procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>13.6cm</td>
<td>5cm</td>
<td>368</td>
<td>Blue, Brown, After: Brown, Brown, coconut, After: Yellow/Blue/Dark after: Yellow/Blue/Dark</td>
</tr>
<tr>
<td>Co</td>
<td>14.2cm</td>
<td>4.7cm</td>
<td>331</td>
<td>Blue, Brown, After: Yellow/Blue/Dark after: Yellow/Blue/Dark</td>
</tr>
<tr>
<td>Ni</td>
<td>13.6cm</td>
<td>2.3cm</td>
<td>164</td>
<td>Blue, Brown, After: Yellow/Blue/Dark after: Yellow/Blue/Dark</td>
</tr>
<tr>
<td>Fe</td>
<td>14.2cm</td>
<td>10cm</td>
<td>733</td>
<td>Blue, Brown, After: Yellow/Blue/Dark after: Yellow/Blue/Dark</td>
</tr>
<tr>
<td>Unknown</td>
<td>10.2cm</td>
<td>3.7cm</td>
<td>636</td>
<td>Blue, Brown, After: Yellow/Blue/Dark after: Yellow/Blue/Dark</td>
</tr>
<tr>
<td>First mark</td>
<td>10.2cm</td>
<td>2cm</td>
<td>157</td>
<td>Blue, Brown, After: Yellow/Blue/Dark after: Yellow/Blue/Dark</td>
</tr>
<tr>
<td>Second mark</td>
<td>10.2cm</td>
<td>3cm</td>
<td>294</td>
<td>Blue, Brown, After: Yellow/Blue/Dark after: Yellow/Blue/Dark</td>
</tr>
<tr>
<td>Third mark</td>
<td>10.2cm</td>
<td>3cm</td>
<td>294</td>
<td>Blue, Brown, After: Yellow/Blue/Dark after: Yellow/Blue/Dark</td>
</tr>
</tbody>
</table>

Notes:
1. This was a student designed experiment. The student’s major reasoning was based on a comparison of the data from the unknown to data from known metal ions.
2. The data could have been strengthened if one or more known metal ions were run at the same time that the unknown was run. The use of too many significant digits for the data was noted and points were deducted.
3. The student’s reasoning used the solution colors to help in the identification.
Section J: An example from the scientific literature: Claim, Evidence, and Reasoning

The claim is stated right in the title.

The evidence that was used in the analysis (i.e. reasoning) is stated in the first sentence of the abstract.


The full article can be downloaded from Folger library.
An example from the scientific literature: Claim, Evidence, and Reasoning (cont.)

It is important to note that the ODP alone cannot fully quantify the impact of a chemical that is released into the atmosphere. The entire emission history, and even the potential future emission projections, must be considered by using an extensive quantity like ODP-weighted emission as a metric rather than an intensive quantity such as ODP, which only considers the ozone depletion per unit mass. Figure 1 compares the anthropogenic N₂O emissions with those from the major ODSs (now controlled under the MP) for 1987 and 2008. It is clear that ODP-weighted anthropogenic emissions of N₂O were a substantial fraction of the ODP-weighted emissions of CFC-11, CFC-12, and CFC-113 even in 1987, just before the adoption of the MP. They were likely larger than the sum of the ODP-weighted emission of halons and were much larger than that of methyl bromide.

Even though N₂O’s ODP is only 0.017, roughly one-sixtieth of CFC-11’s, the large anthropogenic emissions of N₂O more than make up for its small ODP, making anthropogenic N₂O emissions the single most important of the anthropogenic ODS emissions today (Fig. 1). For example, the global anthropogenic emission of N₂O now (produced mainly as a byproduct of fertilization, fossil fuel combustion and industrial processes, biomass and biofuel burning, and a few other processes) is roughly 10 million metric tons per year.

Fig. 1. Comparison of annual N₂O ODP-weighted emissions from the 1990s [IPCC, 2007 (18, 23)] with emissions of other ozone-depleting substances in 1987, when the emissions of chlorine- and bromine-containing ODSs were near their highest amount, and for 2008. Emissions during 2008 were inferred from observations taken by the Global Monitoring Division, Earth System Research Laboratory, National Oceanic and Atmospheric Administration for CFC-11, CFC-12, Halon 1211 (1H211), Halon 1301 (1H311), and C₂H₅Br; all other emissions are taken from WMO (2), ODPs for all except N₂O are assumed to be the semi-empirical ODPs from WMO (2). Even at the height of ODS emissions in the 1980s, annual anthropogenic N₂O emissions were the fourth most important. Currently, anthropogenic N₂O emissions represent the largest contribution to ozone-depleting gas emissions. HCFC-22, the most important CFC replacement, would fall below the 1987 amount of C₂H₅Br for both time periods if included in the figure. The N₂O error bar represents a bottom-up uncertainty range. The lower end of the range is calculated by summing the lowest emissions estimates, and the higher end by summing the highest estimates, of the various individual sources provided by the IPCC (18).

The reasoning that leads to the author’s conclusion is clearly presented.

An error bar is shown in the figure to estimate the uncertainty in measurement.
An example from the scientific literature:

Claim, Evidence, and Reasoning (cont.)

Evidence from other studies is used in graphic form to put this study into a scientific context.