Credibility Errors and Learning Error Analysis in MSE Lab Classes

Joanna Millunchick and Timothy Chambers
Department of Materials Science and Engineering

Introduction

Error analysis is a core skill required for conducting experimental and theoretical work in STEM fields. STEM practitioners use error analysis to determine the significance of a result, to choose appropriate tools for analyzing data, and to make decisions about the usefulness of data.

Prior to this study, we found that students in our MSE courses received little formal instruction in the principles and application of error analysis. Interactions with students suggested low student ability and self-efficacy in this area. In addition, we observed anecdotally that students seemed particularly prone to credibility errors when using computers in their laboratory classwork. In this context, credibility errors may be identified as *gullibility errors* (where students treat a computer as being more credible than it actually is) and *credulity errors* (where students treat a computer as being less credible than it actually is).[1] In particular, our experiences suggested that students were prone to gullibility errors when conducting data analysis tasks.

These two observations led us to a set of research questions, which are the focus of the present work.

Research Questions

- How prone are students to credibility errors when using computers as part of their experimental work?
- Do students primarily commit gullibility errors, or do they also commit credulity errors?
- How do students' experiences in the lab class affect their self-efficacy regarding error analysis?
- Do students' error analysis skills and self-efficacy correlate with their commission of credibility errors?

Methodology

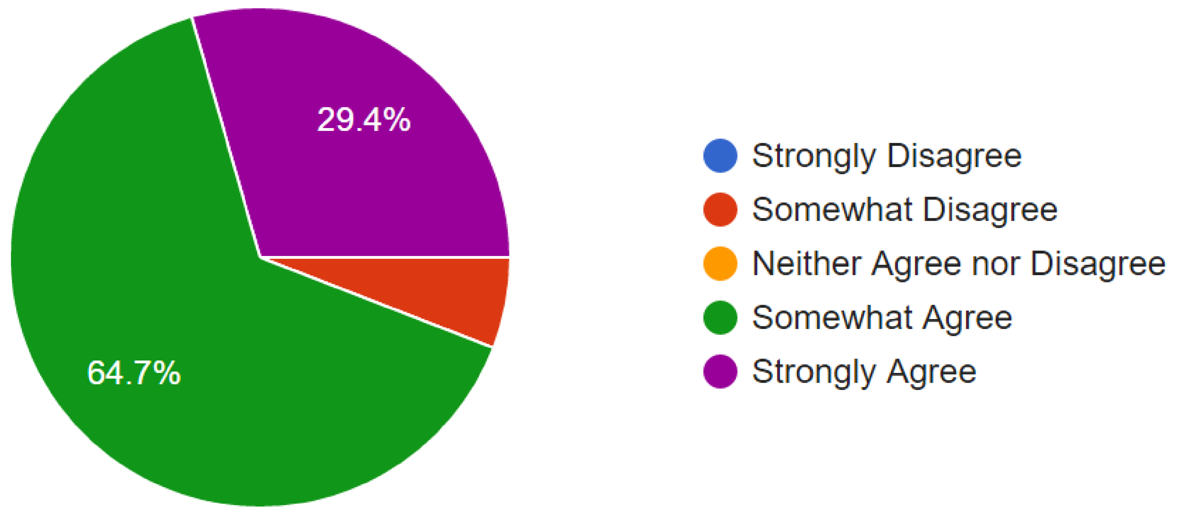
This study focuses on MSE360, which is a junior-level laboratory class that is required for all MSE majors. Over the past year, we made significant changes to the structure and content of MSE360 alongside conducting informal observations and interviews of students and collecting preliminary assessment and survey data. The outcomes of this first year will influence the continued evolution of MSE360 and inform the more rigorous data collection to follow in Fall 2016.

In Summer 2015, we redesigned MSE360 to follow the lifecycle of a material system as students synthesize, characterize, test, and compare their own samples through the semester. Instruction in error analysis was added to the curriculum. We designed activities where students used both manual and computer-based techniques for working with their data. This design created situations in which we could observe students having the opportunity to commit credibility errors based on both their implicit biases and explicit thinking about error analysis.

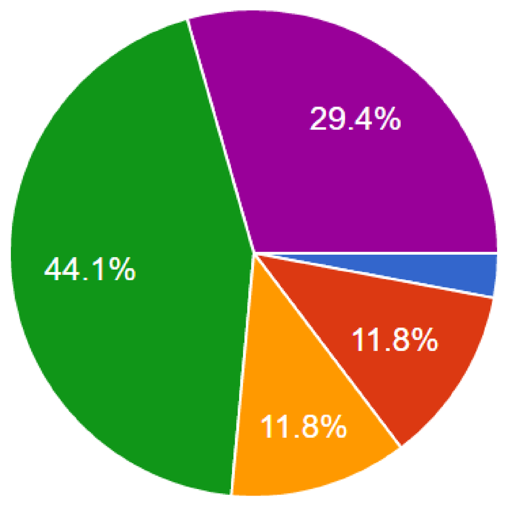
For assessing student outcomes, we included a written final exam in the course, and administered an optional survey for students who continued to MSE365 (the second lab course). The final exam contained three context-rich questions in which error analysis was relevant and credibility errors might be committed. The survey contained a variety of Likert-scale items probing students' beliefs and self-efficacy about error analysis, as well as a free-response question that many students used to provide additional feedback.

Assessment and Survey Results

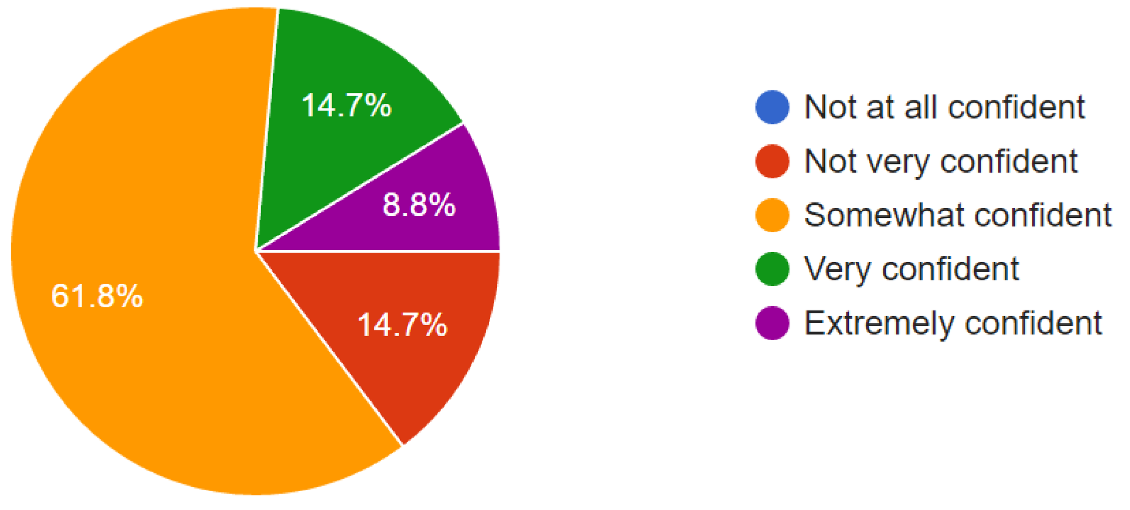
MSE360 helped me to improve my understanding of discussion and analysis of error in experiments.



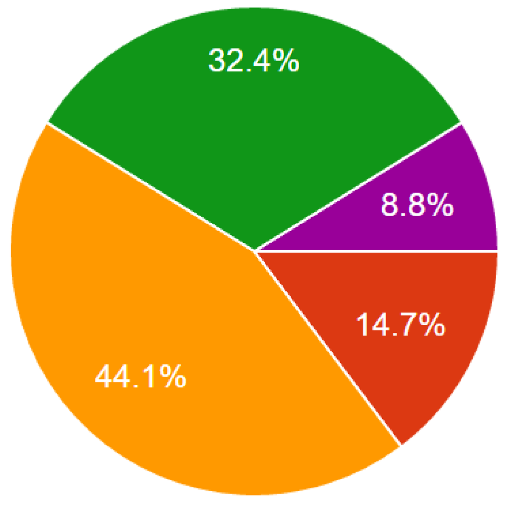
MSE360 helped me to improve my understanding of error propagation.



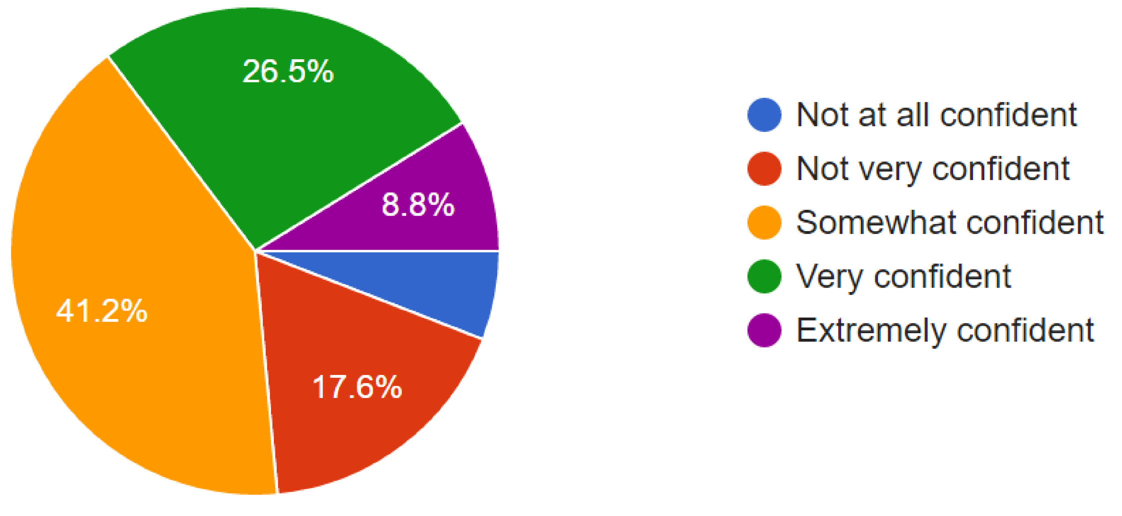
How confident are you in your ability to discuss your error analysis in a lab report or other written document?



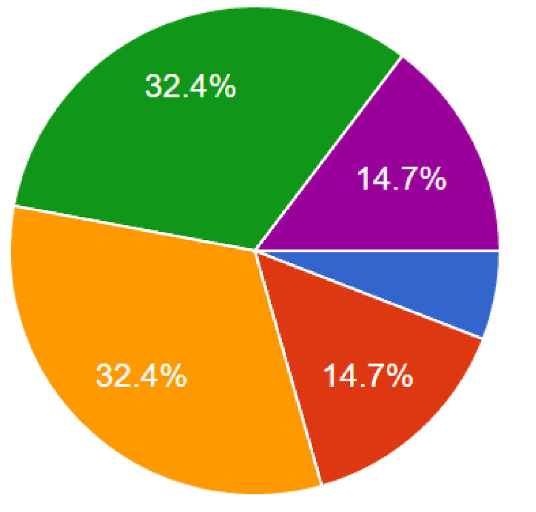
How confident are you in your ability to determine the most precise way to analyze experimental measurements?



How confident are you in your ability to critique someone else's error analysis?

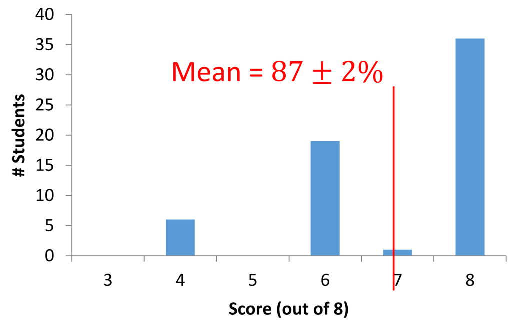


How confident are you in your ability to perform error propagation on experimental data?

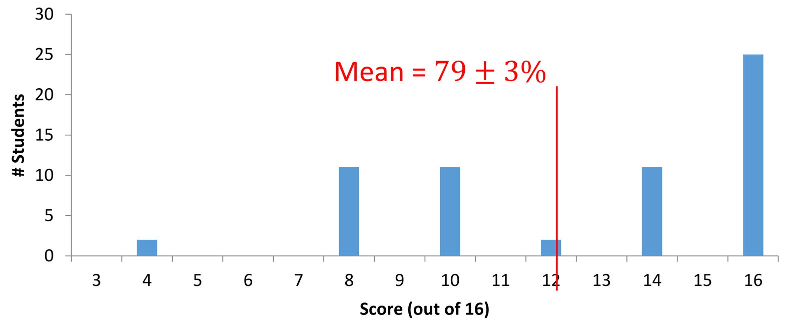


Results from the three error analysis items on the final exam are shown below. Item 3 required students to determine the number of significant figures appropriate for a value read from a phase diagram. Item 5 required students to calculate the uncertainty in a mole fraction calculated from values on the phase diagram. Item 7 asked students to explain how the uncertainty calculated in Item 5 could be minimized. For Item 7, answers regarding experimental technique, data analysis methods, or both were accepted as correct.

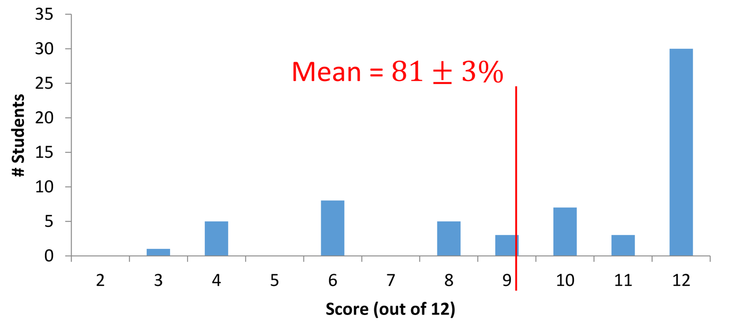
Assessment Item 3 Scores



Assessment Item 5 Scores



Assessment Item 7 Scores



Students performed significantly higher on Item 3 than on Item 5 ($p<0.01$) and Item 7 ($p=0.05$). Comparing survey and exam results suggests that students have less confidence than is warranted by their true ability in error analysis. While studies have shown that high-performing students tend to self-assess below their true ability,[2] a variety of context-specific variables (e.g. gender, math background, grading methods) may be at work here and should be investigated further.

Student Quotes

Survey

"I think having more in class activities in lecture in regards to error analysis and propagation would have been helpful and made me more confident in my abilities to analyze data with error."

"I do understand reporting the final values and knowing when a range is too large for confident conclusions. "

"I understand the theory of how to apply error propagation when given formulas [but] I still find it confusing when determining what the error propagation is when you just have data from lab."

"It was very good for us to learn about error analysis in a low-pressure setting, before graduating and entering the research or industry world where large error or incorrect analysis could be much more detrimental."

Exam

"Using [software and manual] methods… whichever method has the least uncertainty (standard deviation) will be used for analysis."

"If you use software there is really no way to reduce the experimental uncertainty, as the software is as precise as it's going to be."

"Try not to use manual work, which is very arbitrary from our experience."

"We can find which process [software or manual] has the lowest uncertainty by allowing multiple people to try each process on a single image and compare the results."

"I will do the optical microscopy analysis to get the image and use ImageJ [software], which is better than manual work…"

Future Work

Our immediate goals are to continue analyzing the Fall 2015 data and use our findings to inform improvements to curriculum, assessments, and surveys for Fall 2016. Our results to date suggest that:

- Credibility errors do occur, but we will need to directly probe student conceptions on the topic to quantify their true rate of occurrence.
- Gullibility errors seem to be the dominant type of credibility error.
- Teaching error analysis techniques equips students to avoid credibility errors via explicit reasoning about uncertainties.

Our preliminary findings also suggest new questions to investigate:

- What variables are driving the gap between self-assessed and actual error analysis ability, and can additional instructional interventions reduce this gap?
- Does instruction in error analysis actually help students overcome fundamental reasoning difficulties and misconceptions that lead to credibility errors?

Acknowledgments and References

We wish to thank Dr. Susan Gentry for her assistance in developing new curriculum for MSE360, and UM-CRLT for funding this ISL project.

1. B. Fogg and H. Tseng, "The Elements of Computer Credibility", Proc. of the SIGCHI Conf. on Human Factors in Computing Systems, 1999
2. D. Boud and L. Falchikov, "Quantitative studies of student self-assessment in higher education: a critical analysis of findings", Higher Education 18(5), 1989