Communication

Teaching errors? A case study of students learning about the analysis of data quality

***Jim Ryder[a] and Ashley Clarke[b]**

[a]*Centre for Studies in Science and Mathematics Education, School of Education, University of Leeds, Leeds, LS2 9JT, UK.*
e-mail: j.ryder@education.leeds.ac.uk
[b]*Department of Physics and Astronomy, University of Leeds, Leeds, LS2 9JT, UK.*
e-mail: phy6arc@phys-irc.leeds.ac.uk

Abstract
This study examined the ways in which a small group of second year university physics students express ideas about sources of error in science, and how these ideas developed as a result of explicit teaching about errors.[1] Prior to teaching, many of these students were unable to provide appropriate qualitative descriptions of sources of error in data. Explicit teaching about errors concepts, interwoven with student project work, resulted in significant improvements in student understanding.

Students' understanding of error analysis

Developing students' ability to assess the quality of data is a key aim of university science courses. Students need to learn how to use quantitative error analysis tools such as analysis of variance or the combination of errors. However, students also need to develop an understanding of *qualitative* aspects of error analysis, such as the distinction between systematic and random errors; such insights will guide them in designing and using measurement procedures. Studies have found that many undergraduate science students have limited insights into how the quality of a data set is assessed. A recent review concludes that: "*Research on undergraduate students' understanding of measurement data and their treatment has revealed that [students] (…) make second measurements only to confirm the first one, tend to reject the variability of repeat measurements, do not grasp the necessity of standard deviation and therefore do not use it when expressing a repeat measurement result*".[2]

For example, studies have shown that many university science students do not distinguish between random and systematic errors[3, 4] or accuracy and precision.[5] In response to these concerns we designed a short sequence of explicit teaching about errors, focused on key errors concepts rather than on quantitative approaches. The impact of this teaching was then evaluated through a detailed case study of the experiences of a small number of university students. We were interested in what they learned about errors, and also in their reflections on previous experiences of learning about errors at school and university.

Teaching about errors

Rather than designing a stand-alone teaching unit on errors analysis, we chose to embed errors teaching within an existing module in which students collect and interpret their own data as part of an electronics project. We felt that this would help students to apply their developing understanding about errors in authentic science contexts. The teaching (conducted by AC) was incorporated within the module at several points over a ten-week period. It included discussion of the meaning of the terms accuracy, precision, random and systematic error, and developed students' application of these terms within the context of their project work.[1] The focus was on qualitative aspects of error analysis. The students involved had already received teaching about the quantitative analysis of data, and were able to apply these formalisms (though not always appropriately). The aim here was to enable these students to identify different types of error, and use these qualitative insights to inform their design of data collection and the appropriate use of quantitative data analysis techniques.

A case study

The subjects were all second year physics students (representing a wide range of academic ability) following an electronics module that included project work in which they collected and interpreted data. (The studies cited earlier suggest that chemistry undergraduates share similar misconceptions about errors.) The case study followed all seven students enrolled on this module.

The small sample size enabled in-depth interviews to be conducted with each student before and after teaching. These reveal the detail of students' understandings and their reflections on the effectiveness of the teaching. Larger scale studies, typically relying upon written responses alone, are unable to provide such insights.

The study began with a detailed analysis of students' understanding about measurement errors using written survey questions and individual interviews. During the teaching students were encouraged to discuss sources of error with the researcher in the context of their ongoing project work. Survey questions and individual interviews were repeated after the teaching to investigate developments in student thinking. In these latter interviews students were encouraged to reflect on previous experiences of errors teaching. All research visits and interviews were conducted by JR, who was not involved in the teaching (or assessment) of the module; this may well have led to greater openness on the students' part.

What did students learn?

Prior to teaching, these second year students exhibited considerable confusion concerning the meanings of key terms associated with error analysis: systematic error, random error, accuracy and precision. For example, the following quote is from an interview with a student who used the terms accuracy and precision interchangeably before teaching: "*Your accuracy on that measurement would be half the lowest reading (…) so it's just how precise you can make a measurement.*"

Several students distinguished between accuracy and precision in terms of features of the measuring system and the actions of the measurer, rather than the nature of the errors themselves: "*Precision that is just how carefully you do it (…) just how careful you do the experiment, you know if you follow it through exactly and don't make any stupid mistakes or anything but accuracy is basically down to the equipment*."

As a result of teaching, students showed significant improvements in their use of errors terminology (systematic, random, accuracy, precision) when prompted to use these terms. Their responses were also more detailed, and drew on their projects to exemplify their ideas. However, even after teaching these students did not tend to use errors terminology *spontaneously* when discussing sources of error in their project. Of course, these students do meet terms such as 'errors' and 'precision' in everyday use. However, the aim here was for students to recognise that these terms have much more specific, and differentiated, meanings in a science context.

The teaching module examined explicitly the main concepts of error analysis. Students were also encouraged to apply these ideas in their analysis of data as part of the project work. Several students made very positive comments about this 'hands-on', integrated approach to errors, contrasting this approach with what they saw as an overly quantitative (and decontextualised) introduction to error analysis given as part of their first and second year laboratory courses: "*In the first two [laboratory courses] we discussed errors an unbelievably large amount, but it was (…) an analytic approach to it. Actually thinking about it in a real situation (…) then trying to treat the errors ourselves: that's where all [my understanding] is coming from.*"

Implications

Many students tend to use computational methods blindly when analysing a dataset. To combat this tendency we suggest that teaching should place greater emphasis on *qualitative* features of error analysis. For example, students could be asked to complete error analysis tasks that only require qualitative reasoning, e.g. 'identify all potential systematic/random errors associated with these measurements'. In reviewing such an activity, concepts of error analysis would need to be presented to students explicitly. Of course, teaching would also need to consider the quantitative analysis of errors in data. Furthermore, students need to be encouraged to apply errors concepts in a range of measurement contexts throughout their undergraduate course.

Acknowledgements

We thank the students involved for their willingness to participate in this research. The study was funded by the Learning and Teaching Support Network (Physical Sciences).

References

1. A full report providing details of the teaching, and the probes used to analyse student learning, can be downloaded from the project website, hosted by the Learning and Teaching Support Network (Physical Sciences): http://dbweb.liv.ac.uk/ltsnpsc/devprojs/undergrad_understanding.htm
2. D. Evangelinos, D. Psillos and O. Valassiades, *An investigation of teaching and learning about measurement data and their treatment in*

the introductory physics laboratory. Paper presented at the 3rd International Conference of the European Science Education Research Association, Thessaloniki, Greece, 21-26 August 2001.
3. M.-G. Séré, R. Journeaux and C. Larcher, *Intern. J. Sci. Ed.*, 1993, **15**(4), 427.
4. F. Lubben, B. Campbell, A. Buffler and S. Allie, *Science Education*, 2001, **85**, 311.
5. J. Tomlinson, P.J. Dyson and J. Garratt, *U. Chem. Ed.*, 2001, **5**, 16.