Making Sense of Measurements, Making Sense of the Textbook

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Abstract. Students who enroll for the special access course in physics at the University of Cape Town generally do not speak English as first language and have experienced poor science teaching. As a consequence students experience a large range of difficulties in trying to learn physics. We discuss research carried out in two such areas (a) understanding of measurement and (b) engagement with the textbook. With regard to (a) an overview of the methodology, analysis framework and findings of previous work will be presented together with more recent preliminary findings regarding audience dependence when conveying measurement results. With regard to (b) the idea of writing chapter summaries was used to guide students through the book with the aim that the textbook would come to be valued an accessible resource. Findings from the analysis of the student summaries are presented

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INTRODUCTION

During the last two decades at the University of Cape Town, Physics Education Research has been conducted in various areas to help students succeed in the "special access" program [1]. One of these areas centers around student understanding of measurement which has lead to the development of a new laboratory course that foregrounds the nature of measurement uncertainty [2]. A more recent facet of this work has revolved around trying to tease out the role of audience when reporting measurement results. A separate area of research has involved student writing such as generating writing intensive laboratory reports [3]. Recent work has been focused on trying to assist students to engage meaningfully with the textbook by having them write chapter summaries. Analysis of these summaries also shows the important role of audience in how student work is interpreted.

MEASUREMENT STUDIES

A study conducted in 1998 probed student understanding about data collecting, data processing, and data comparison [4]. The instrument that was developed centered around a single context in which a ball is rolled down a slope (placed on a table) from a height h, and the distance d that the ball lands from the base of the slope is measured. In the questions, students are asked to evaluate various scenarios in which they have to choose between different actions that could be carried out, and explain the reasoning behind their choice. It is important to emphasize that the focus of the analysis was the reason provided in the free writing response and not the choice of action.

Initially, a system of student "progression" along more sophisticated views of measurement was used to categorize the data [4]. However, further analysis of the responses found that student reasoning could be expressed as following from two underlying constructs: the "point paradigm" and the "set paradigm" [5].

In the "point paradigm," each measurement is viewed akin to an "artifact." Thus, a collection of data is viewed simply as an ensemble of independent and unconnected pieces of information. On the other hand, subscribing to the "set paradigm" implies regarding each datum as providing partial information about the measurand. Thus, this view moves beyond that of an ensemble to that of a set by constructing distributions from which parameters such as the best approximation of the measurand and an interval of uncertainty can be derived. Thus, while the point paradigm is not regarded being appropriate for scientific measurement, the set paradigm reflects accepted scientific practice.

Changes in Instruction

The studies referred to above indicated that traditional laboratory courses did not appear to be to be effective in changing the mindset of students from the point to the set paradigm when dealing with measurements in the first year physics laboratory. This

finding was not confined to the special access students but was also seen in the physics majors who entered the mainstream degree directly. A recent study of the latter at the University of Cape Town showed that only about a fifth of the sample in question could be regarded as having exited the laboratory course with a deep understanding of measurement uncertainty [6].

One of the problems identified with traditional instruction is the use of the "frequentist" approach to measurement. Based on the recommendations of the International Standards Organisation a data analysis course was designed around the "probabilistic" approach in which the interpretation of uncertainty is associated with the inference that is made about a measurand. The same formalism also applies equally to one or many data points.

The Physics Education Research group created a workbook as part of the special access laboratory curriculum: "Introduction to Measurement in the Physics Laboratory: a probabilistic approach" [2]. A recent evaluation [7] indicated that students in the special access program were three times more likely to exit their course with a consistent "set paradigm" view than those exiting from traditional instruction who did not use this workbook.

Role of Audience

Despite the success reported above, student understanding still appears to be fragile and continuous reinforcement of the ideas is necessary. One reason for this may be that although the system in place is now logical and self-consistent it is not immediately apparent as to how it links with students' everyday experience with measurement. To phrase the question thus, what resources, based on everyday experience, might be activated such that when refined though a process of sense-making steps might lead naturally to the need for uncertainties and uncertainty intervals to be reported in the science context.

A program of probing student engagement with measurement at a more fine-grained level is presently underway. As a first step, the information reporting aspect of measurement is being investigated from the perspective of what influence (on framing and activation of resources) different audiences might have when posited as the target for the same information to be reported. The idea that different contexts can activate different resources is discussed in detail in Hammer et. al. [8]. The extension here is to consider how the role of audience influences student' framing.

Effect of Audience Questionnaire

A study was conducted to test the role of audience in student reporting of data. These probes were given during the fall term of 2008 to the special access students at the start of their instruction. The posited scenario given to students is shown in the box below. (This is part of a broader instrument that is not discussed here. Only the questions relating to audience are shown.)

> *"You are provided with a bottle of white powder. Carefully weigh out a sample of 32.3 grams of the white powder, then pour the sample into a beaker filled with water. "*
> You go to a digital mass balance in the laboratory and slowly add the powder to the balance until the reading on the scale shows 32.3g. There are another five identical balances in the laboratory so you carefully take your sample and place it on each balance in turn. The five readings that you obtain are as follows:
> 32.4 g 32.1 g 32.3 g 32.4 g 32.2 g

The questions on the questionnaire pertaining to the role of audience are as follows:

1. The lecturer comes to you and asks "What is the mass of the powder you have there?" What do say to the lecturer? ***My <u>words</u> to the lecturer are…***
2. A friend called Bugs who is also doing the same thing comes to you and asks "What is the mass of the powder you have there?" What do say to Bugs? ***My <u>words</u> to Bugs are…***
3. Finally you have to write up a scientific report. In the report how will you state the mass of the powder that you used? ***In my report I would state that the mass of the powder that I used was…***

Each question also required students to explain their reasoning in detail. (Bugs is a persona used throughout the first year curriculum, and is defined to be a friend who is good at math but does not know physics.)

Student Responses to Questionnaire

Thirty of the student questionnaires were randomly selected and used to create a coding scheme. This was then used to then code 50 of the remaining student questionnaires in detail. It was found that the explanations could be sorted into seven categories, and a few could not be coded, mostly because students answered with irrelevant information, possibly misinterpreting the question. A brief explanation of the categories is:

- Single reading: students reported their result based on a single reading selected from the six given readings.
- Average: Students calculated and reported the average of the readings.
- Interval: Students indicated that their results fell into a certain range and they would report that range.
- Authority: Students reported their results referred to what they were required to have for the experiment, namely 32.3g.
- Personal: Students reported results they felt confident that they had actually measured with explanations such as "because this is the value *I* measured."
- Uncertain: Students were uncertain as to what amount they had and what to report.
- Plagiarism: Students refused to tell Bugs their mass because then Bugs would be guilty of plagiarism.

The plagiarism category is interesting to note. This response was not at all anticipated but made sense after learning the students had to fill in a declaration on academic conduct earlier in the day that included issues surrounding plagiarism. This emphasizes the delicacy of such probes as prior experience has a strong influence on how students may frame the question.

Each student's questionnaire was coded based on the type of explanation they gave, and what the audience was for that particular explanation (the lecturer, Bugs, or the report). The details of the coding are shown in Figure 1.

Of the 50 students, 13 (26%) used consistent reasoning when responding to the three different audiences. The majority of students, 37 (74%), reported differently to at least one of the three audience types. 50% of the students reported differently between the lecturer and Bugs, while 62% reported differently between the lecturer and the report. 68% of students reported differently between Bugs and the report and 32% reported differently to all three audiences.

Among those who used consistent reasoning for two of the three audiences, 13 students (26%) used consistent reasoning for Bugs and the lecturer, and an alternate reasoning for the report. 3 students (6%) used consistent reasoning for Bugs and the report, and an alternate reasoning for the lecturer. 6 students (12%) were consistent in their reasoning for the lecturer and the report, but used an alternate reading for Bugs. Interestingly, 4 of those 6 students responded to Bugs with the plagiarism response, which may have been different had they not had the previous academic conduct lecture. Without this, the number of students who used consistent reasoning for all three audiences may have been higher, though students may still have chosen a different explanation for Bugs.

What is surprising about this is there was as big a change in student reporting between the lecturer and the report as there was between the lecturer and Bugs. At first glance one might think that the audience is actually the same for both the lecturer and the report because both eventually go to the same place – to the lecturer for evaluation. However, there is also a difference between telling someone what result you obtained versus writing it in a report. Writing it formalizes it, and makes it a permanent record of your work. Students could be trying to mimic scientific writing [9], or they could be thinking that more formalism is needed in written reporting than oral reporting.

STUDENT TEXTBOOK SUMMARIES

In a separate effort to help students in the special access course engage with the textbook and prepare for class, students wrote 1-page summaries of the text chapters during the spring semester, 2007. This project is reported in detail in a separate paper in this volume [10]. These summaries were due before the content was covered and students could revise them or bring their original summaries to use for aid during the exams. The purpose was to help students realize that the textbook is a resource and could help them take charge of their own learning.

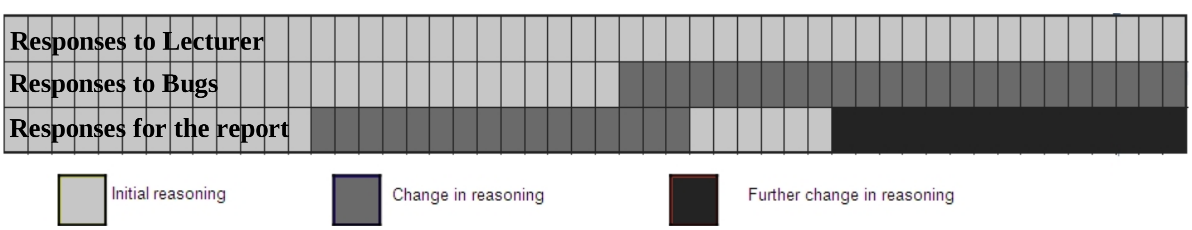

FIGURE 1. Simplified student response map for the questionnaire. The vertical columns are for each individual student while the rows represent the particular audience in question.

A secondary purpose derived from this effort was to quantify the quality of the summaries. This was desired as part of an ongoing effort to quantify writing in order to do controlled, research-based studies of writing-to-learn. Writing literature calls for more quantitative data and calls the link between writing and learning an open question [11-13]. A framework was developed for quantitative analysis of the summaries and qualitative data was obtained via student interviews and a brief survey.

The framework was based on Waywood [14], which defined three cognitive levels of writing: recounting, summarizing, and dialoguing. A subset of the student summaries were coded in detail, independent instructors rated the summaries, and an independent coder tested the framework. The framework was found to be valid and reliable, and easily usable by other researchers: quantitative analysis matched with qualitative rankings by independent researchers, and coding matched between independent coders.

As explained in detail in [10], this project achieved its two aims of helping students engage with the textbook, and developing a quantitative measure of the quality of student summaries. While we found we could measure their external quality, we can't actually tie this into the internal reflective state of the students. How the students chose to explain the information they included in their summaries would depend strongly on factors such as their level of understanding, the amount of time put in, and other factors that cannot be gauged from their work alone. Correlating summaries to learning or as a measure of student reflection requires additional qualitative data.

In addition, each student was writing for a different audience: themselves. Everyone has a different purpose, different needs, and will choose to include different things in their summaries. This factor makes any comparisons between students invalid, as they are not writing for the same audience. Therefore if a study is to be done in the future using this framework, it will be necessary to define an audience, such as Bugs that the students should address in the writing. This will make the audience the same for each student and allow for valid cross-group comparisons in a controlled study.

CONCLUSIONS

This paper highlights some of the work done by the Physics Education Research group at the University of Cape Town primarily with special access students. The work has helped uncover important understandings of how students report data, leading to a successful lab manual focused on measurement. Further studies with this issue show the impact of audience on how students choose to report data, and emphasize the need to carefully frame questions so students activate productive resources. An additional project on textbook summary writing showed that students were empowered by this activity, and it helped them engage with the text. We could measure the external quality of the summaries, but not the internal reflective state of the student. In addition, the role of audience confounds the ability to compare student work directly, since each student was writing for him or herself.

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